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ACTA PHYSIOLOGICA SCANDINAVICA

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VOL. 33. SUPPLEMENTUM 117.

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CEREBELLAR REPRESENTATION OF HIGH THRESHOLD AFFERENTS IN THE SPLANCHNIC NERVE

WITH OBSERVATIONS ON THE CEREBELLAR PROJECTION OF HIGH THRESHOLD SOMATIC AFFERENT FIBRES

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LENNART WIDÉN

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VOL. 33 SUPPLEMENTUM 117.
FROM THE DEPARTMENT OF CLINICAL NEUROPHYSIOLOGY,
SERAFIMERLASARETTET, STOCKHOLM

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Ivar Hæggströms Boktryckeri AB.
Stockholm 1955

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PREFACE

To Professor ERIC KUGELBERG I offer my sincere gratitude for placing the facilities of his laboratory at my disposal and for the friendly and stimulating interest with which he has followed this work. His advice and generous support as well as the excellent relations prevailing in the department have been invaluable.

I am greatly indebted to Professor C. G. BERNHARD for introducing me to the problems of spinal cord physiology and initiating me in the experimental technique during the time I worked in his laboratory.

I am deeply grateful to Dr. BERNHARD FRANKENHAEUSER for his kindness in reading the manuscript and for his able criticism and helpful suggestions.

I wish to express my warm appreciation to my friend and colleague, Dr. LARS-ERIK LARSSON, for his continued interest and helpfulness.

Finally my deep gratitude is due to Miss RUTH HEDÉN for the translation of this paper and for her generous help and valuable technical assistance throughout the course of this work.

The investigation has been partly supported by a grant from Stiftelsen Therese och Johan Anderssons minne.

Stockholm, January 1955.

LENNART WIDÉN

GENERAL INTRODUCTION

Until about 15 years ago the cerebellum was considered to be concerned solely with the regulation of motor function—"the head ganglion of the proprioceptive system"—which received, in addition to its cerebro-cerebellar connections, impulses only from proprioceptors of muscles, tendons, joints and labyrinths. The classical pathways of Gower and Flechsig were assumed to be the principal fibre systems for the transmission of spinal impulses to the cerebellum. The anatomical and physiological investigations of recent years, however, have necessitated a modification of this concept. Electrophysiological studies have shown that impulses from other groups of receptors also pass to this organ: tactile (SNIDER and STOWELL, 1942; ADRIAN, 1943), auditory (STOWELL and SNIDER, 1942), visual (STOWELL and SNIDER, 1942) and olfactory (HUGELIN, BONVALLET, DAVID and DELL, 1952). The cerebellar projection of impulses from muscle proprioceptors has also been confirmed with this technique (DOW and ANDERSON, 1942; GRUNDFEST and CAMPBELL, 1942; MOUNTCASTLE, COVIAN and HARRISON, 1952; CARREA and GRUNDFEST, 1954). Neuroanatomical studies have revealed the existence of additional pathways for impulses from the spinal cord to the cerebellum. Recently BRODAL (1953), who has carried out pioneering work in this field, defined anatomically not less than eight possible pathways between the spinal cord and cerebellum.

The possibility of a somatotopic as well as a functional localization in the cerebellum has long been discussed. The results of neuroanatomical studies have not always shown agreement with electrophysiological data. On the other hand, the latter have often been found to be at variance. Afferent pathways from the periphery and higher centres to the cerebellum as well as efferent pathways from the cerebellum have been studied in these investigations. A brief account of investigations on afferent projection systems from the periphery only will be given here.

DOW (1939) and DOW and ANDERSON (1942), who recorded the

cerebellar responses to electrical stimulation of various nerves in the fore- and hindleg of decerebrate cats and of rats in nembutal anaesthesia, found no evidence of somatotopic organization in the cerebellar areas from which responses were obtained: the entire anterior lobe, lobulus simplex, pyramis and paramedian lobules. On the other hand, SNIDER and STOWELL (1942, 1944) have reported with physiological tactile stimulation the presence of discretely localized face, forelimb and hindlimb sensory areas in the cerebellar cortex of anaesthetized cat and monkey. The receiving areas for impulses of tactile origin were located in three parts of the cerebellum: one in the posterolateral half of the ipsilateral anterior lobe and two in the paramedian lobules. In each lateral half of the anterior lobe there was a projection of the ipsilateral half of the body surface in which the feet and vibrissae were the parts most conspicuously represented. In the lateral part of this area there was the representation for the feet, with the hindpaw most rostral, and in the medial part the trunk and head, with the hip most rostral, and posterior to this the shoulder region which overlapped the caudally placed head zone. The forefoot and hindfoot of one side were represented in both paramedian lobules, the forefoot having a stronger contralateral representation than the hindfoot. ADRIAN (1943), independently of these authors, reported in the cat and monkey definite topographical localization in the cerebellum for responses evoked by mechanical stimulation, such as touch, pressure, movements of joints and muscle stretch. WHITLOCK (1952), in a combined neurohistological and neurophysiological study of the avian cerebellum, found a definite somatotopic arrangement of the activated loci of the cerebellar cortex into tail, leg, wing and face tactile areas.

These experimental results of SNIDER and STOWELL, of ADRIAN, and of WHITLOCK strongly favour a somatotopically organized projection of the tactile afferent system to the cerebellum. This raises the question whether one of the known pathways between the spinal cord and cerebellum satisfies the requirements for a somatotopically arranged spinocerebellar projection for these tactile impulses. BRODAL (1949, 1953), who has studied this problem, concluded that the only system possible was the spino-

lateral reticular nucleus-cerebellar. The lateral reticular nucleus receives ascending afferents from the lateral funiculus of the spinal cord which terminate in the nucleus where they are systematically organized, the fibres from the hindleg in the superficial parts and those from the foreleg in somewhat deeper parts. Those parts of the nucleus which receive spinal afferents project to the cerebellar tactile receiving areas. BRODAL was further able to demonstrate that those parts of the nucleus which project to the foreleg area in the anterior lobe are identical with those which receive spinal fibres from the foreleg. The electrophysiological studies of BERRY, KARL and HINSEY (1950) and BOHM (1953) have shown that the afferent impulses which enter the spino-lateral reticular nucleus-cerebellar system derive from coarse cutaneous nerves.

The importance of the part played by anaesthesia in mapping studies of specific sensory projection areas in the cerebral cortex has long been recognized. Very deep anaesthesia is often necessary. The effect of anaesthesia on the cerebellar responses evoked by electrical stimulation of various dorsal roots and peripheral nerves as well as by physiological stimulation of tactile end organs has been systematically studied by COMBS (1954). This author found no evidence of somatotopic localization in *unanaesthetized* preparations. On the other hand, in animals in *nembutal anaesthesia* a precise confirmation of foreleg and hindleg afferent localization was noted. COMBS' observations on the effect of anaesthesia on cerebellar localization may explain the somewhat controversial results of earlier workers.

With regard to functional localization in the cerebellum only the question of whether different sensory modalities have separate areas of representation in the cerebellum will be discussed. Also on this point the results of different authors have varied. DOW and ANDERSON (1942) found, in the rat, that impulses from proprioceptive receptors projected mainly to the pyramis, while "exteroceptive stimulation" (touch) evoked responses primarily in culmen. Accordingly, they considered they were able to demonstrate at least a degree of localization for these modalities. MOUNTCASTLE, COVIAN and HARRISON (1952) stimulated various peripheral nerves and found that stimulation of Group I and III fibres of a purely muscle nerve in the hindleg resulted in an

anterior lobe localization of evoked potentials identical to that found with stimulation of a purely cutaneous nerve. Likewise, CARREA and GRUNDFEST (1954) found that the anterior lobe receiving area for impulses from cutaneous nerves in the foreleg and hindleg conveyed by the ventral spinocerebellar tract considerably overlapped that for impulses from muscle nerves conveyed by the dorsal spinocerebellar tract. Similar results were reported by COMBS (1954) in unanaesthetized preparations.

SNIDER and STOWELL (1944) have shown that the auditory and visual cerebellar projection areas are almost conterminous and occupy predominantly lobulus simplex and tuber vermis. Rostrally these projection areas overlap the tactile response areas for the face and partly that for the forepaws. The audiovisual area often extends to the paramedian lobules and consequently here also overlaps the tactile area. HUGELIN and co-workers (1952) have shown that also the third type of distance receptors, olfactory sensory cells, project to lobulus simplex as well as to both paramedian lobules and to pyramis. DELL and OLSON (1951) found that the vagus visceral afferent fibres have a cerebellar representation. This was located in the posterior part of the anterior lobe and the anterior part of lobulus simplex and overlapped the receiving areas for olfactory, auditory and visual impulses as well as that for tactile impulses from the face.

Thus the majority of the investigations would seem to indicate that there is considerable overlapping of the projection areas of different afferent systems.

The first purpose of the present investigation was to determine whether the afferent neurones distributed with the sympathetic outflow to the viscera have a cerebellar representation. This was found to be the case. A study was then made of the type of fibres mediating the afferent impulses and their spinal pathways, as well as the sensory modality they subserve. Since it was found that the splanchnic afferent fibres which mediate the cerebellar responses belong to the delta group, experiments were performed to determine whether delta fibres from other sources also have a cerebellar representation.

MATERIAL AND METHODS

Cats were used in all the experiments. Most of the animals were anaesthetized with intravenous nembutal. The level of anaesthesia was varied according to the experimental needs, the initial dosage being about 20—25 mg/Kg body weight. A few experiments were performed on decerebrate preparations. The animals were initially anaesthetized with ether or trilene and decerebration performed either by transection at a collicular level and removal of the entire cerebrum or by subpial aspiration of the left occipital pole, which exposed the mesencephalon, followed by division of the brain stem by aspiration from the superior colliculus down to a point just behind the mammillary bodies.

For both stimulation and recording chlorided silver electrodes were used. When recording from the cerebral and cerebellar cortices as well as from the dorsum of the spinal cord the exploring electrode was on the surface of the structures with the second electrode resting on adjacent non-neuronal tissue. The recording electrodes were so arranged that a positive potential was recorded as a downward deflection of the cathode beam.

The left splanchnic nerve was exposed through a retroperitoneal approach and severed at its point of junction with the coeliac ganglion. In most experiments the nerve was dissected free only to the point where it enters the diaphragm. For recording the afferent volley in the sympathetic trunk several of the lowest ribs were resected and the animal was then maintained by artificial respiration after the administration of curare. All the exposed cord and nerves as well as the exposed cerebellar cortex were covered with liquid paraffin except in the case of the splanchnic nerve when recording from the sympathetic trunk. The liquid paraffin and the rectal temperature of the animal were maintained at a constant temperature of 37—38° C by radiant heat. When recording from the sympathetic trunk only a small stretch of the trunk was dissected free and divided at the proximal end. The sympathetic trunk and the splanchnic nerve were immersed

in a pool of warm Ringer's solution (cotton wool saturated with the solution). The proximal stimulating electrode (cathode) on the splanchnic nerve, connected to earth, and one of the recording electrodes on the sympathetic trunk were in the pool of Ringer's solution, while the second of each pair of electrodes was in the air. Essentially the same technique was employed when stimulating and recording from the superficial radial nerve.

The stimuli consisted of single rectangular pulses, mostly of 0.1 to 0.5 msec. duration. The action potentials were fed to an RC-coupled amplifier and recorded on a cathode ray tube. The cathode ray trace was photographed on to bromide paper.

A. CEREBELLAR REPRESENTATION OF HIGH THRESHOLD AFFERENTS IN THE SPLANCHNIC NERVE

Earlier Investigations of Splanchnic Afferent Fibres and Their Central Connections

It has long been known (LANGLEY, 1896; RANSON and BILLINGSLEY, 1918) that visceral afferent fibres have their cell bodies in the posterior spinal root ganglia. At the thoracolumbar level of the spinal cord they travel with the sympathetic nerves from the viscera in the sympathetic trunk and via the white rami communicantes to the posterior roots. Recent experimental electrophysiological investigations (AMASSIAN, 1951 b; AIDAR, GEOHEGAN and UNGEWITTER, 1952) have shown that afferent impulses from the splanchnic nerve of cat are conveyed *partly* via the ipsilateral fasciculus gracilis and nucleus gracilis, the internal arcuate fibres and the contralateral medial lemniscus to reach the contralateral nucleus ventralis posterolateralis of the thalamus and *partly* via the anterolateral funiculus in the region of the lateral spinothalamic tract on both sides.

The investigations of AMASSIAN (1950, 1951 a, b) and DOWNMAN (1951) have shown that there is a cerebral cortical representation for afferent fibres in the splanchnic nerve of rabbit, cat, dog and monkey and that the impulses are mediated by the A beta group of afferent fibres.

It is known that the coarse afferent fibres in the splanchnic nerve—the A beta group—are at least partly derived from the Pacinian corpuscles in the mesentery (EDGEWORTH, 1892; SHEEHAN, 1932). GERNANDT and ZOTTERMAN (1946) found that the Pacinian corpuscles in the cat mesentery were extremely sensitive to the gentlest pressure. They recorded afferent impulses from the corpuscles in the mesentery and the splanchnic nerve. The impulses were conducted at a fast speed and originated in large myelinated fibres which, in the splanchnic nerve, had a diameter of 6—10 μ and numbered about 300. Further, they found that the splanchnic nerve contained, in addition to the coarse fibres,

fine myelinated fibres, 2—3 μ in diameter and numbering over 10,000. Injurious stimuli, such as pinching of the intestinal wall or mesentery, gave rise to slow action potentials from delta and C fibres only, a finding which these authors stated supports the view that both the intestinal wall and the mesentery are supplied with afferent fibres capable of producing nociceptive reactions to mechanical stimuli which cause nociceptive reflexes when applied to the skin.

The central connections of these small fibres in the splanchnic nerve are less well known. Aidar and co-workers found slow impulses (10—6 m/sec) ascending in the spinal cord in the region of the lateral spinothalamic tract on both sides after stimulation of the splanchnic nerve, but they did not state whether the stimulus strength required to evoke these impulses was the same as that required to evoke delta fibre impulses.

Although the investigations of recent years have contributed greatly to our knowledge of the central connections of the visceral afferents, little is yet known about their functional significance and the sensory modalities they subserve.

RESULTS

I. Cerebellar Responses

a. *Potential form.* A single shock to the central cut end of the splanchnic nerve evoked potential changes in the cerebellar cortex. The form, amplitude and duration of these potentials as well as their distribution were largely determined by the type and depth of anaesthesia. The majority of the experiments in the present study were performed on cats in moderate nembutal anaesthesia (25—40 mg/Kg body weight intravenously). Fig. 1, A to F, from one of these experiments in fairly light anaesthesia shows the cerebellar response in three different areas of the cerebellar cortex following stimulation of the left splanchnic nerve.

In records A and D the recording electrode was on the third folium of culmen anterior to the primary fissure, 0.5—1 mm. medial to the left paravermian vein, in B and E on the second folium of the left paramedian lobule posterior to the intercrural fissure, and in C and F on the third folium of the right paramedian lobule. Records D, E and F were taken at higher sweep speed to facilitate measurement of the latencies.

The potential changes recorded in A and D are representative for the type of response obtained in the maximally activated area of this region. The initial deflection is positive with a latency of about 20 msec. and a duration of about 20 msec. In a series of 11 experiments on anaesthetized preparations, the latency to the initial positive phase varied between 18 and 22 msec., and the duration between 10 and 20 msec. Sometimes the entire response consisted only of a positivity, but this was generally followed by a negativity of lower amplitude and longer duration, as seen in record A. The threshold for the negative wave was frequently slightly higher than that for the initial positive wave.

From the large number of investigations with the evoked potential technique on the representation of different sensory systems in the cerebral and cerebellar cortices we know that the primary

responses recorded monopolarly from the surface of the cortices show no essential differences, regardless of which sensory system is activated and to which region of the cerebral or cerebellar cortex the pathway projects and from which the responses are accordingly recorded. The predominant features of these evoked responses are an initial surface positive wave and a following slower negative wave. Thus, the same elements that constitute the cerebellar response to splanchnic nerve stimulation (Fig. 1 A.). In accordance with earlier analyses and interpretations of evoked potentials in the cerebral cortex (BISHOP and O'LEARY, 1936; CURTIS, 1940, ADRIAN, 1941; MARSHALL et al., 1943), in monopolar recording from the surface of the cerebellum, the initial positivity has been interpreted as a sign of the approach of impulse volleys to the cortex and has been used as an index in mapping the representation of sensory systems in the cerebellar cortex (DOW and ANDERSON, 1942; SNIDER and STOWELL, 1944).

It is not the purpose of the present study to analyse further the different components of evoked cerebellar potentials. The responses evoked by electrical stimulation of the splanchnic nerve were, however, routinely investigated with regard to the threshold values of the different phases, the frequency sensitivity and the reactions to local or intravenous strychnine or anaesthetic agent as well as to asphyxia. The results obtained are in complete agreement with those of earlier workers (BREMER, 1952; BREMER and GERNANDT, 1954; and others) with regard to cerebellar responses evoked from other sources.

Sometimes a negative potential of short duration was seen ascending from the initial positive deflection of the splanchnic cerebellar response (Fig. 1 B.). Such a negative "spike" was also found by BREMER (1952) in especially good preparations. In responses from the splanchnic nerve the spike was generally of longer duration than in the records of acoustic responses published by BREMER, probably the result of greater dispersion of the afferent impulses due to the longer conduction distance.

Fig. 1, G to M, shows the responses in different regions of the cerebellar cortex evoked by electrical stimulation of the left superficial radial nerve in the same preparation as in records A to F, for comparison with the responses evoked from the splanch-

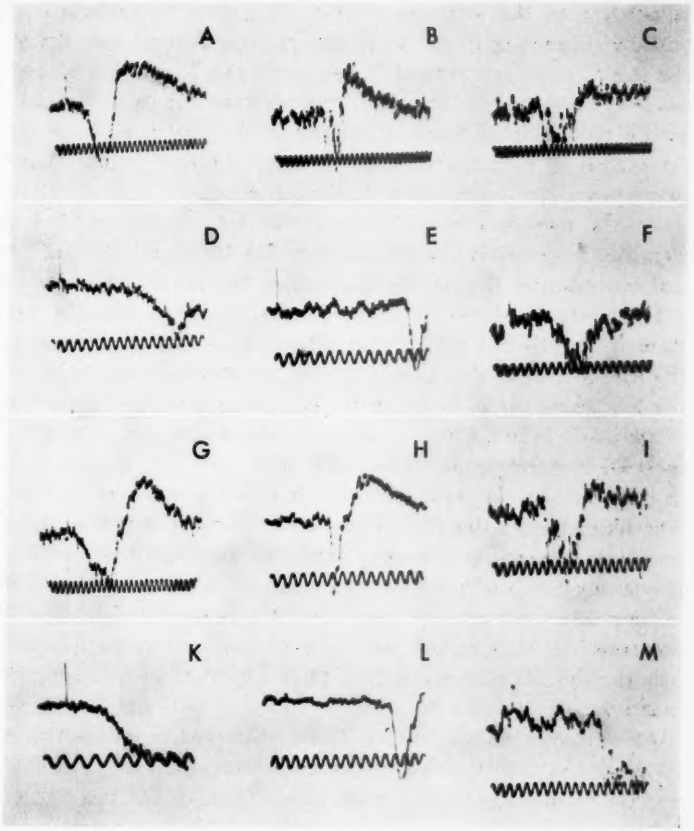

Fig. 1. Responses evoked by stimulation of the left splanchnic nerve (A—F) and the left superficial radial nerve (G—M) in the area of maximal activity in culmen (left column), left paramedian lobule (middle column) and right paramedian lobule (right column). Time: A, B, C, F, H, I, 250 c/s; in remaining records 500 c/s.

nic nerve. In this preparation in fairly light nembutal anaesthesia an evoked response with a latency of about 5 msec. (records G and K), was obtained from the most posterior folia of culmen, lateral to the left paravermian vein. No cerebellar positive potential with such a short latency was observed in response to

stimulation of the splanchnic nerve. This may be explained in part by differences in the fibre size and conduction velocity of the two afferent nerves used (see below) as well as in the central pathways they utilize. It is also possible that the early response in the posterolateral parts of culmen evoked by stimulation of the superficial radial nerve was conveyed by a system other than that which conveyed responses to the other parts of the cerebellum where the responses have a considerably longer latency; 20 and 22 msec. respectively for responses in the ipsilateral (H and L) and contralateral (I and M) paramedian lobules.

Latency differences of this order between responses in the maximally activated area of the anterior lobe and, e. g., those in the paramedian lobules have not been observed on stimulation of the splanchnic nerve. In Fig. 1, the latency to the initial positivity of the response in the anterior lobe was about 20 msec. (A and D), in the ipsilateral paramedian lobule 25.5 msec. (B and E), and in the contralateral paramedian lobule about 24 msec. (C and F). The difference in the latencies of the responses in the anterior lobe and the paramedian lobules was of the same order of size (5—6 msec.) also in other experiments. On the other hand, differences in the latencies of the responses in the ipsilateral and contralateral paramedian lobules were not consistently found. The threshold for the response in the different areas was approximately the same.

Also SNIDER and STOWELL found with tactile stimulation a difference in the latencies of the responses in the anterior lobe and the paramedian lobules, while BOHM (1953) found with electrical stimulation of cutaneous nerves that the latencies were more or less the same in the three areas. Records of responses to stimulation of the splanchnic as well as the superficial radial nerve sometimes showed an early surface negative wave preceding the surface positive wave (see Fig. 1, C and I, and Figs. 2 and 3). This was seen most often in the responses from the paramedian lobules but was not definitely observed in those from the maximally activated area of the anterior lobe.

SNIDER and STOWELL also noted that the surface positive wave of the cerebellar response was occasionally preceded by a small surface negative wave.

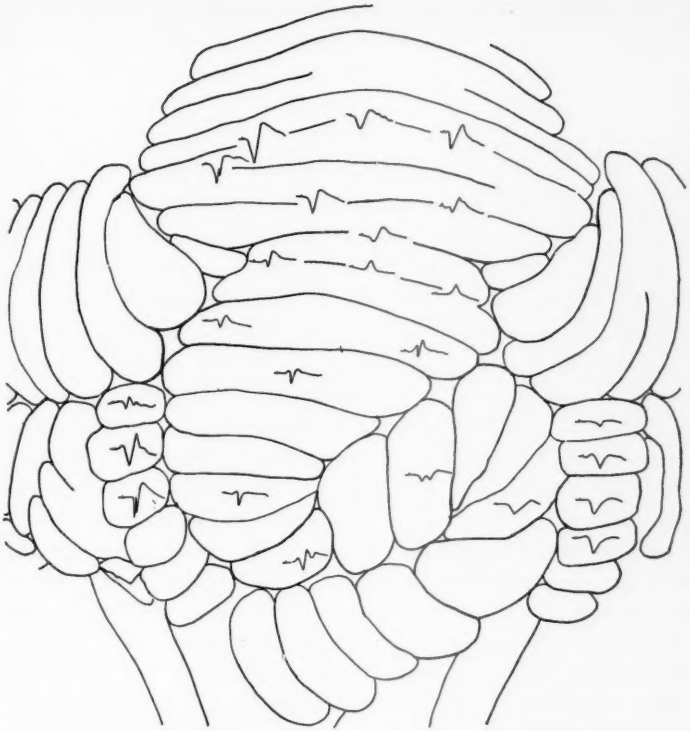

Fig. 2. Responses in the cerebellum evoked by stimulation of the left splanchnic nerve in lightly anaesthetized cat.

b. *Distribution of the splanchnic cerebellar responses.* Figs. 2 and 3 show the results of two mapping experiments performed on cats anaesthetized with intravenous nembutal. The experiment illustrated in Fig. 2 was performed in light anaesthesia (25—30 mg nembutal/Kg body weight) and recording began approximately two hours after the last dose of nembutal. In the experiment illustrated in Fig. 3 the cat was under deeper anaesthesia (35—40 mg nembutal/Kg body weight) and the last dose was given less than one hour before the commencement of recording. The differences in the form and distribution of the responses in the two

experiments are in all probability due to differences in the depth of anaesthesia. Since the cats were not decerebrated and the tentorium was left in situ, only the most posterior folia of culmen could be explored. Only a small part of crus anterior and posterior was exposed on both sides and no attempt was made to record from them. Consequently, the results shown represent an incomplete map of the cerebellar receiving areas. A more extensive exposure would have been desirable, but the cerebellum is very sensitive to circulatory and blood pressure disturbances and only in good preparations can satisfactory responses be obtained. Furthermore, in my experience, it is more difficult to obtain good responses to stimulation of the splanchnic nerve than to stimulation of cutaneous nerves. Also on decerebrate preparations responses with about the same latency as in cats in light anaesthesia were readily obtained. If, however, the tentorium was removed and large areas of the cerebellum exposed no satisfactory responses were obtained, probably due to circulatory disturbances.

Fig. 2 shows the initial positivity with the largest amplitude and the shortest latency recorded from the third folium of culmen anterior to the primary fissure immediately medial to the left paravermian vein. Thus this region may be considered as the maximally activated area in this case. Responses with an initial positive wave of approximately the same latency but lower amplitude were recorded, however, also from other posterior parts of culmen, thus, from a relatively extensive area. Posterior to the primary fissure the responses were generally polyphasic with a more or less pronounced initial negative phase. The latency to the succeeding positivity was longer than that to the initial positive phase in responses from the anterior lobe. In the contralateral half of the vermian part of lobulus simplex monophasic negative potentials were recorded.

The mapping experiment illustrated in Fig. 3 shows essentially the same conditions as that in Fig. 2, but the amplitude of the responses was generally lower and the area for the responses with an initial positive phase was more restricted, comprising solely the ipsilateral half of the most posterior folia of culmen, with the maximum point 0.5—1 mm medial to the left paravermian

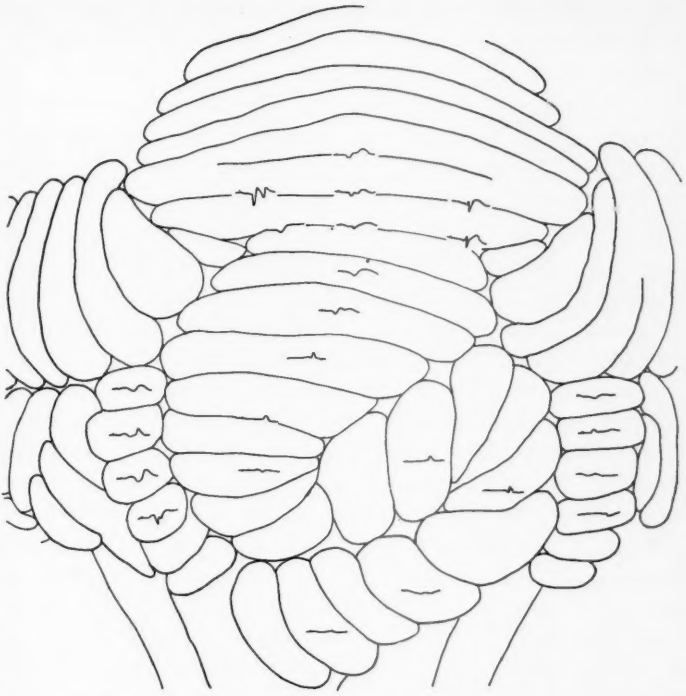

Fig. 3. Responses in the cerebellum evoked by stimulation of the left splanchnic nerve in cat in moderately deep anaesthesia.

vein, and the vermian part of lobulus simplex. In the left (ipsilateral) paramedian lobule the maximal responses were recorded from the 3rd and 4th folia posterior to the intercrural fissure. They showed an initial negativity. From the contralateral paramedian lobule practically no significant positivity was recorded but, as from the folium and tuber vermis, only small negative deflections. From the pyramis no significant responses were recorded.

It is evident that the distribution of evoked potentials is largely determined by the depth of anaesthesia. Transitory states of localization and non-localization could be produced by varying

the depth of anaesthesia. Fig. 2 from an experiment under light anaesthesia shows widespread distribution of the evoked potentials, but with clearly differentiated maxima: one in the anterior lobe near the left paravermian vein, one in the second and third folia of the left paramedian lobule and one in the third and fourth folia of the right (contralateral) paramedian lobule. In preparations in deep anaesthesia evoked responses were not obtained with certainty from the right paramedian lobule (Fig. 3). Experiments in which large doses of nembutal were administered successively showed that the response from the maximally activated area in the anterior lobe was that most resistent to the anaesthetic agent and persisted, but of lower amplitude, after the responses from the other regions had been eliminated.

Accordingly, the mapping showed that the splanchnic nerve projection areas in the cerebellum coincide in the paramedian lobules with the projection areas for tactile impulses from the extremities as mapped by SNIDER and STOWELL. The splanchnic anterior lobe projection area is slightly medial to the tactile projection areas for the extremities and anterior to the area for the vibrissae, as found by the same authors. It overlaps, however, the area of representation for the limbs and the face as well as the projection areas for the vagus (DELL and OLSON, 1951) and olfactory nerves (HUGELIN, BONVALLET, DAVID and DELL, 1952).

II. Splanchnic Origin of the Cerebellar Responses

The experiments illustrated in Figs. 1 to 3 showed that electrical stimulation of the splanchnic nerve evoked potentials in the cerebellar cortex. The stimulus strength required to elicit these potentials produced, however, another effect as well, viz., a viscero-motor reflex with efferent discharge in the intercostal and lumbar nerves, resulting in reflex twitches of the body wall. There existed therefore a possibility that this movement might activate receptors in the body wall and set up a volley of impulses, and that the cerebellar response was secondary to this volley and consequently not of splanchnic origin.

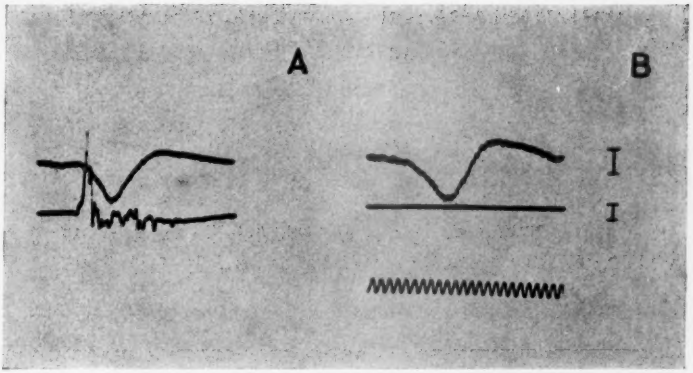

Fig. 4. *Upper tracings* show the response in the ipsilateral posterior part of culmen, and *lower tracings* the reflex discharge in abdominal muscles recorded with needle electrodes, following stimulation of the left splanchnic nerve. In A before, and in B after, intravenous injection of 1.9 mg/Kg d-tubocurarine. Time: 250 c/s. Calibration: 50 μV (upper tracings) and 200 μV (lower tracings).

Fig. 4 illustrates an experiment to test this possibility. The upper tracings show the cerebellar response in the posterior part of culmen and the lower tracings the response in abdominal wall muscles, before (A), and after (B), the intravenous injection of d-tubocurarine-chloride in a dose of 1.9 mg/Kg body weight, which completely abolished the action potential in the abdominal wall muscles as well as all visible and palpable movements. The respiratory muscles were, of course, also paralyzed and the animal was maintained by artificial respiration. Curarization had no obvious effect on the cerebellar response.

It was also possible that at the stimulus strength employed other nervous structures in the abdominal wall might be activated by current spread and set up the cerebellar responses. To exclude this possibility several experiments were performed in which the splanchnic nerve was crushed proximal to the stimulating electrodes. This procedure regularly abolished the evoked cerebellar response. If the cathode of the stimulating electrodes was moved proximal to the site of injury the response returned. This clearly showed that the cerebellar response was of splanchnic origin and that no effective stimulus escaped to other nervous structures.

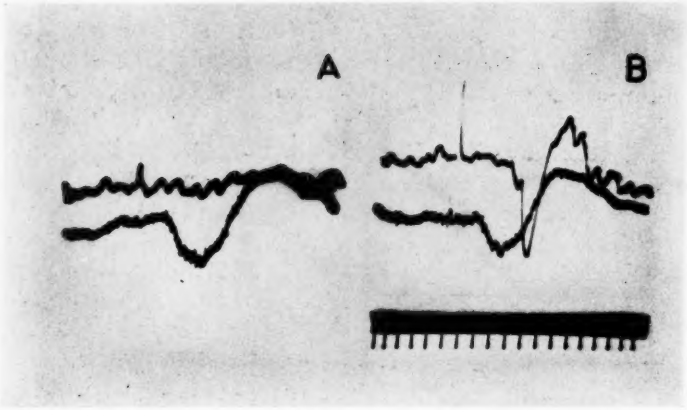

Fig. 5. *Upper tracings* show the response in the posterior part of culmen, and *lower tracings* the response in the contralateral sensory area I, to stimulation of the left splanchnic nerve. The stimulus strength was in A, subliminal and in B, maximal, for the cerebellar response. Time markers: 1 and 5 msec.

III. Types of Splanchnic Afferent Fibres Represented in the Cerebellum

Since, according to AMASSIAN (1951 b), the A beta group of the splanchnic afferent fibres is responsible for the primary evoked responses in the cerebral cortex, it might be expected that they are also responsible for the cerebellar projection of the splanchnic nerve. It was, however, clear even in the first experiment that the threshold for the response evoked from the splanchnic nerve was considerably higher than that for the response from cutaneous nerves, e. g. the sural or superficial radial. A comparison of the threshold and latency for the response in the cerebral cortex with that of the response in the cerebellar cortex to stimulation of the splanchnic nerve yielded further information.

One such experiment is illustrated in Fig. 5. The lower tracing in record A shows the response in sensory area I of the cerebral cortex at a stimulus strength which was subliminal for the cerebellar response in the posterior part of culmen (upper tracing). Not until the stimulus strength was approximately ten times the threshold value for the response in sensory area I was a response

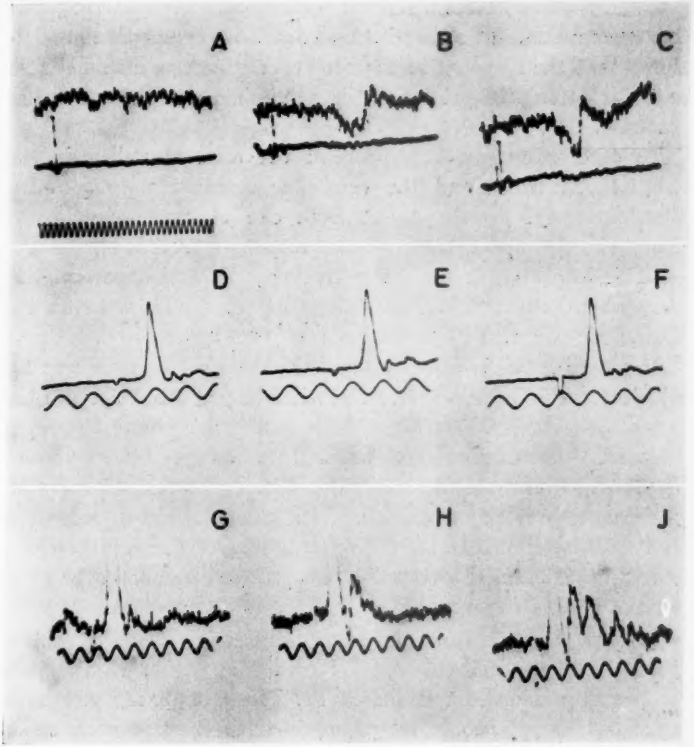

Fig. 6. A—C: *Upper tracings* show the response in the ipsilateral posterior part of culmen, and *lower tracings* the action potential in the sympathetic trunk at Th 10, evoked by stimulation of the splanchnic nerve. Relative value of the stimulus strength was in A, 1.7; in B, 3.3; in C, 6.7. (Threshold value for the cerebellar response was 2.7.)

D—J, from the same preparation, show the response in the sympathetic trunk to stimulation of the splanchnic nerve. Conduction distance was 7.0 cm. D—F, with low, and G—J with high, amplification. The stimulus strength was in D, half the threshold value for the cerebellar response; in E, the threshold value; in F, 2.5 times the threshold value. The action potential of A beta fibres reached its maximum with a stimulus that was half the threshold value for the cerebellar response.

Relative value of the stimulus strength was in G, 1 (which evoked action potentials from purely A beta fibres); in H, 1.7; in J, 2.7 (threshold for the cerebellar response). Time: A—C, 500 c/s; D—J, 1000 c/s. Further description in text.

evoked in the cerebellum. Record B shows the cerebellar response to maximal stimulus strength. A comparison of records A and B shows that the response in the cerebral cortex was maximal at a stimulus strength that was still subliminal for the cerebellar response.

To further analyse this problem the afferent volley in the sympathetic trunk and the cerebellar response were recorded simultaneously. Fig. 6, A—C, from one of these experiments shows, in the upper tracings, the responses recorded from the anterior lobe and, in the lower tracings, the action potential in the sympathetic trunk. The stimulating electrodes were on the splanchnic nerve.

In record A the relative value of the stimulus strength was 1.7, which was subliminal for the cerebellar response but 5 times the threshold for the A beta fibres. In record B the stimulus strength was twice that of A and submaximal for the cerebellar response. In C it was maximal (relative value 6.7). The threshold value for the cerebellar response was 2.7. From a comparison of records A and C it is clear that the action potential of the A beta fibres reached maximum at a stimulus strength that was still subliminal for the cerebellar response.

Records D to F from the same preparation show the action potential of the afferent volley recorded at higher sweep speed to permit a more detailed analysis. The stimulating electrodes were on the splanchnic nerve proximal to the coeliac ganglion and the recording electrodes on the sympathetic trunk at the level of Th 10. The conduction distance was 7.0 cm. In record D the stimulus strength was half the threshold value for the cerebellar response, in E the threshold value, and in F, 2.5 times the threshold strength. Thus, it is again shown that the action potential of the A beta splanchnic fibres reached its maximum at a stimulus strength that was considerably below threshold for the evoked cerebellar response.

The latency to the initial small component of the action potential—poorly shown in the records—was 0.9 msec., which corresponds to a conduction velocity of 77 m/sec. This is certainly a high value for the coarse splanchnic nerve fibres but also AMASSIAN found, in about one half of his preparations, that the action

potential of a very small fibre group, the A beta 1, preceded the main A beta component. Its maximum conduction velocity was between 70 and 81 m/sec., and he pointed out that nerve fibres with diameters corresponding to these velocities have been described in the sympathetic outflow.

The latency to the main component of the action potential was 1 msec., which corresponds to a conduction velocity of 70 m/sec. Assuming a spike duration of 0.4 msec., a velocity of about 61 m/sec. may be given for the slowest fibres contributing to the action potential in Fig. 6, D to F.

Records G to J, show the sympathetic trunk action potential recorded with high amplification. In G is seen the action potential of fibres with conduction velocities ranging from about 77 to about 54 m/sec. followed by small, insignificant deflections. The relative value of the stimulus strength was 1.0. In H, at a stimulus strength of 1.7, there is a second later elevation with a latency of 2 msec., corresponding to a conduction velocity of 35 m/sec. At a stimulus strength of 2.7, which was the threshold value for the cerebellar response, there appeared a still later third elevation with an amplitude almost equal to that of the second elevation (Fig. 6 J), followed by several elevations of lower amplitude. The third elevation had a latency of 2.9 msec., and a duration of 1.3 msec., and may therefore be considered to be the action potential of afferent fibres with conduction velocities of 24 to 22 m/sec.

AMASSIAN, in his analysis of the action potentials of different fibre groups in the splanchnic nerve found, with high stimulus strengths, deflections with maximal conduction velocities of 29 to 35 m/sec. and 21 to 24 m/sec. which appeared after the main A beta component was completed. He was of the opinion that they corresponded to the A gamma-delta groups. His values for these fibres are in general agreement with those found in the present investigation.

The fourth and fifth deflections in Fig. 6, J, correspond to conduction velocities of about 17 and 13 m/sec. respectively. They might be repetitive discharges in any one of the earlier activated fibre groups but they might also be a sign of activation of new fibre groups of smaller diameter.

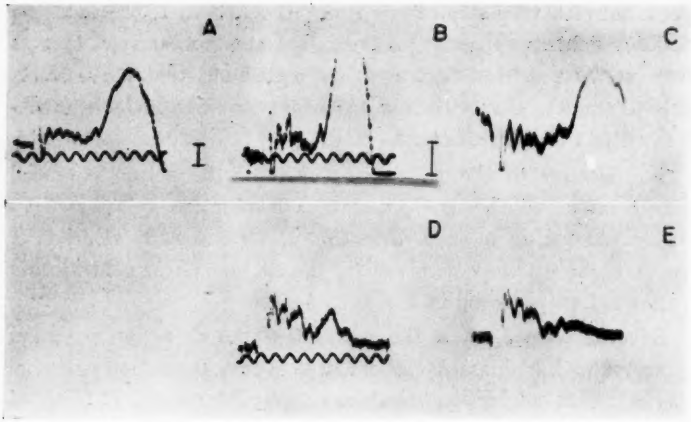

Fig. 7. The action potential in the sympathetic trunk evoked by stimulation of the splanchnic nerve. The stimulus strength was in A—C, 10 times the threshold value for the cerebellar response and in D—E, the threshold value. C and E show superimposed the action potentials evoked by repetitive stimuli delivered at the rate of about 100/sec. Time: 1000 c/s. Calibration: 50 μV. The calibration mark in B applies also to C, D and E.

Fig. 7 illustrates an experiment in which these late elevations in the compound action potential were further analyzed. Records A and B show the afferent volley in the sympathetic trunk recorded at a point 7.0 cm. craniad to the stimulating electrodes on the splanchnic nerve proximal to the coeliac ganglion. The stimulus strength was 10 times the threshold for the cerebellar response. A large late elevation is seen with a latency of 5.5 msec. The fastest fibres contributing to this action potential had a conduction velocity of 13—12 m/sec. The small fibres which gave rise to the potential must be very numerous and probably comprise both delta and B groups of fibres. With the amplification used in record B only the lower parts of the ascending and descending limbs of the late potential are seen. C shows superimposed the responses to repetitive stimuli delivered at a frequency of about 100/sec.; the amplification is the same as that of B. The latency and duration of the late action potential are seen to have increased and the amplitude diminished, while the amplitude of the earlier small potentials, which signal the activation of the A gamma-fast

delta group of fibres, was not significantly reduced. Since B fibres are known to have a subnormal period of 100—300 msec., it seems justifiable to ascribe the changes in the late elevation to relative refractoriness in these fibres. Proof that the potential was not a reflex discharge is given by the fact that it persisted unaltered after section of the ipsilateral thoracic spinal roots and was still present several minutes after the cat was killed.

Record D shows the afferent volley in the sympathetic trunk evoked by a stimulus that was threshold strength for the cerebellar response. This stimulus strength was liminal also for the late elevation in the compound action potential recorded in the sympathetic trunk as well as for the preceding small elevation with a latency of 4.5 msec. Repetitive stimuli at the rate of about 100/sec. considerably decreased the amplitude of the late potential (E).

On the basis of the results obtained in the experiments illustrated in Figs. 6 and 7, it seems reasonable to conclude that the cerebellar response to stimulation of the splanchnic nerve is not the product of excitation of fibres with a conduction velocity faster than 20—24 m/sec. A comparison of records B and C and of records D and E in Fig. 7, shows that the action potentials which are the response of delta fibres[1] with a conduction velocity of 21—15 m/sec. are not increased in size by augmentation of the stimulus strength from the threshold value for the cerebellar response to 10 times this value, while the late elevation, which is the response of fibres with a conduction velocity of less than 15 m/sec. is considerably increased in size. Therefore it seems likely that once the stimulus strength is liminal for the cerebellar response, the recruitment of these fibres is responsible for the increase in size of the response with increasing stimulus strength.

It was possible, though unlikely, that the later deflections obtained with high stimulus strength represented repetitive firing of A beta fibres and that this repetitive firing evoked the responses in the cerebellum. To test this possibility experiments

[1] The maximal conduction velocity for the delta group fibres reported by various workers has ranged from 20 m/sec. to 40 m/sec. In the present study the term "delta fibres" is used to indicate fibres whose action potentials consist of well-defined elevations in the compound spike potential of the nerve headed by a velocity of 24—20 m/sec.

were performed with iterative stimuli (2 shocks) delivered at intervals of 0.5 to 5 msec., at a strength which was maximal for the action potential of the A beta fibres but was subliminal for the cerebellar response to single shock stimulation. This type of repetitive stimulation, however, evoked no response from the cerebellum.

Nor on preparations made extremely excitable by the intravenous injection of strychnine (usually about 1 mg/Kg) did stimulation of the splanchnic nerve evoke a cerebellar response until the stimulus strength was increased to activate delta fibres.

IV. Sensory Modality of the Splanchnic Afferent Impulses to the Cerebellum

Pain impulses from the skin are considered to be conducted not only by the C fibres but also by the delta group fibres (HEINBECKER, BISHOP and O'LEARY, 1933, 1934; ZOTTERMAN, 1936, 1939). It was therefore considered worthwhile to investigate whether stimulation of the splanchnic afferent delta fibres produced nociceptive reactions. Experiments were performed on cats in light chloralose-nembutal anaesthesia (chloralose 40 mg and nembutal 20 mg/Kg body weight) to study the effect of splanchnic nerve stimulation on the pupil and the arterial blood pressure. In other experiments the reflex response of the trunk muscles was recorded.

Fig. 8 shows the effect of stimulation of the central cut end of the left splanchnic nerve on the arterial blood pressure in the right common carotid artery. Single shocks, approximately 0.3 msec. in duration, were applied at a frequency of about 25 a second. Higher and lower frequencies were found to be less effective. In record A the relative value of the stimulus strength was 1, which was the lowest stimulus strength capable of producing a measurable increase in blood pressure. In record B the stimulus strength was increased two and a half fold. Records C and D from the same preparation show the action potential in the sympathetic trunk recorded with low amplification at a distance of 8.0 cm. from the stimulating electrodes on the splanch-

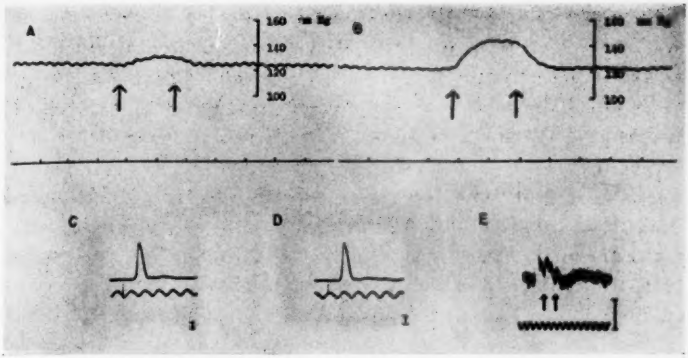

Fig. 8. A and B: Effect of stimulation of the proximal cut end of the splanchnic nerve on arterial blood pressure. Arrows indicate the beginning and end of stimulation. Relative value of the stimulus strength was in A, 1; in B, 2.5. Pulse duration: 0.3 msec. Stimulus frequency: 25/sec. Time markers: 30 sec.
C—E: The afferent volley in the sympathetic trunk evoked by stimulation of the splanchnic nerve. Conduction distance: 8.0 cm. Stimulus strength was in C half the threshold value, and in D and E the threshold value, for a blood pressure increase. Calibration: C and D, 100 μV; E, 50 μV. Time: 1000 c/s. Further description in text.

nic nerve. The stimulus strength in record D was the same as that in A, and in C one half this strength. It will be seen that the amplitude of the action potential was the same in the two records. Accordingly, it may be concluded that the coarse fibres in the splanchnic nerve which produced the action potential were not responsible for the blood pressure reaction.

In record E the recording electrodes were at the same level on the sympathetic trunk as in D, and the stimulus strength was the same, but a higher amplification was used. The record shows superimposed the action potential following each stimulus in a train of shocks delivered to the splanchnic nerve at the same frequency as in records A and B. The action potential of the beta fibres was followed by two elevations (marked by arrows) which signal the activation of fibre groups with a maximal conduction velocity of about 33 and 20 m/sec., respectively. The threshold for the second elevation was the same as that for the blood pressure effect. These elevations were followed by a slow negative wave with a latency of 5.5—6 msec. This

wave had the same characteristics as the late elevation in the compound action potential analysed in the experiment illustrated in Fig. 7, and was interpreted as the sign of activation of slow delta fibres and B fibres. The stimulation threshold for the response was the same as that for the blood pressure effect, but at the stimulus strength used to elicit the latter the late potential was considerably decreased (as in record E).

The effect of stimulation of the central cut end of the splanchnic nerve on the pupil was observed while the eyes were exposed to a constant light which caused pupilloconstriction before the commencement of stimulation. It was found that the stimulus required to produce definite pupillodilation was the same as the threshold stimulus for a blood pressure increase. Thus, to obtain these two reactions required a stimulus strength that activated delta fibres the fastest of which had a conduction velocity of about 20 m/sec. Pupillary dilatation occurred promptly within a few seconds of the commencement of stimulation.

Stimulation of the splanchnic nerve evoked a reflex discharge in the abdominal and lower intercostal muscles. In a few experiments the threshold value for this reflex was compared with that for pupillary dilatation. It was found that the stimulation threshold for the two responses was identical. Experiments were then performed in which the reflex response in a lower intercostal or upper lumbar nerve was recorded concomitantly with the cerebellar response to splanchnic nerve stimulation. Fig. 9 illustrates one of these experiments. The upper tracings show the response in the posterior part of culmen and the lower tracings the reflex discharge in abdominal muscles recorded with needle electrodes. The stimulus strength in A was subliminal for both responses, in B just liminal, in C submaximal and in D maximal. It is evident from the figure that the threshold for the two responses was the same and that with progressively increasing stimulus strength they showed a parallel increase in size.

Comment to Sections III and IV. The experimental results in this investigation indicate that the threshold for nociceptive reactions to afferent splanchnic stimulation is the same as that for the cerebellar response. The question, however, may be raised

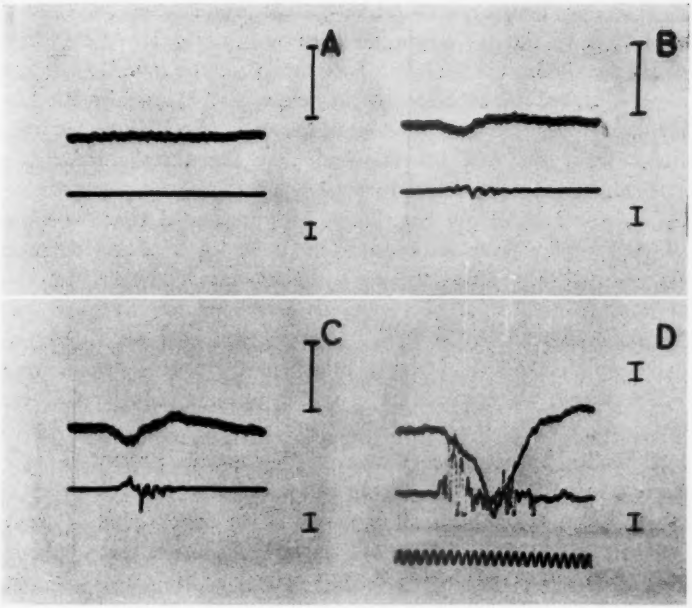

Fig. 9. *Upper tracings* show the response in the ipsilateral posterior part of culmen, and *lower tracings* the reflex discharge recorded in abdominal muscles with needle electrodes, following stimulation of the left splanchnic nerve. The stimulus strength was in A subliminal for both responses, in B just liminal, in C submaximal, and in D maximal. Time: 250 c/s. Calibration: 50 μV (upper tracings) and 200 μV (lower tracings).

as to the specificity of these reactions as a sign of noxious stimulation. Pupillodilatation has for many years been used as a test reaction to such a stimulus and when both this reaction and the blood pressure increase are obtained within a few seconds of the commencement of stimulation, it is considered not to be a humoral effect.

URY and GELLHORN (1939), and others, have shown that the pupillodilatation response to afferent stimulation results solely from inhibition of oculomotor constrictor activity. The response is still preserved after section of the cervical portion of the sympathetic trunk and adrenalectomy does not essentially alter

it. HARRIS, HODES and MAGOUN (1944), who studied the central pathways of the reflex pupillodilatation evoked by stimulating the central cut ends of the splanchnic, sciatic and trigeminal nerves, stated that these pathways are not identical with the classical spino-thalamic tract—the presence of which in the cat, however, is not yet proven—and that the threshold for the pupillodilator response to either splanchnic or sciatic nerve stimulation was exceedingly low. These authors added that "the use of the pupillodilator response as an indicator of either somatic or visceral pain would appear to be open to question." In the present investigation, however, the pupillodilator response was obtained first with a stimulus strength which activated the splanchnic delta fibres. On the other hand, stronger stimuli were not required, which would have been expected had solely C fibres been responsible for this reaction.

The third nociceptive reaction studied in the present investigation, reflex contraction of the abdominal and lower intercostal muscles, has long been used as a sign of activation of nociceptive afferent fibres following stimulation of abdominal viscera (pinching, distension, etc.) or the splanchnic nerve and its branches (MILLER and SIMPSON, 1924; LEWIS and KELLGREN, 1939; DOWNMAN and MCSWINEY, 1946; and others). Recently AMASSIAN (1951 b) and DOWNMAN (1953) showed on cats, and BAISSET and co-workers (1952) on dogs, that the multineurone arc type of reflex discharge in the lower intercostal and upper lumbar nerves which produces twitches of the abdominal wall is evoked first on activation of the small A fibres in the splanchnic nerve with a conduction velocity of less than 30 m/sec., and that these fibres are distinct from those which project to the cerebral cortex.

Respiratory increases, another conventional nociceptive reaction, were not studied in the present investigation. The reflex movements of the intercostal muscles make this a less suitable test in analyses of the splanchnic afferent fibre pathways.

It is not, of course, possible to draw any definite conclusion with regard to the sensory modality of impulses elicited by electrical stimulation of afferent nerves in animals. The specificity of the reactions used here is somewhat questionable. BISHOP (1946),

however, states that "dilatation of the pupil, respiratory and circulatory increases even more than skeletal muscle contraction are specific enough to be taken conventionally as signs of painful stimulation even under anaesthesia."

V. Spinal Cord Potentials Evoked by Stimulation of the Splanchnic Nerve

To obtain some information about the spinal connections of the splanchnic afferent fibres responsible for the cerebellar potentials, experiments were performed in which the slow dorsal cord potentials (GASSER and GRAHAM, 1933; BERNHARD, 1953) evoked by stimulation of the splanchnic nerve were recorded. Fig. 10 illustrates such an experiment. A, B and C were recorded with the exploring electrode on the dorsal cord 0.5—1 mm. from the midline at the level of the lower part of the Th 11 segment. Records D, E and F show the action potentials of the afferent volley in the sympathetic trunk. The distance between the recording electrodes on the sympathetic trunk and the stimulating electrodes on the splanchnic nerve was 5.5 cm. In Fig. 10, A and D, the stimulus strength was subliminal for the slow negative spinal cord potential, whereas the A beta spike had already reached 87 % of its maximal value. In Fig. 10, B and E, in which the stimulus strength was twice that in A and D and just liminal for the spinal cord potential, the A beta spike had reached its maximal value and was of the same amplitude in record F, where the stimulus strength was maximal for the slow spinal cord potential and 3 times the value in A and D. Essentially similar results were obtained on recording from the different spinal levels (Th 6 to L 1) to which the splanchnic nerve belongs. A more detailed account of these experiments will be given elsewhere.

Thus, the results of the experiment illustrated in Fig. 10 clearly showed that the slow negative potential recorded from the dorsal cord in response to stimulation of the splanchnic nerve was not the product of activation of the coarse fibres, which in this experiment had a conduction velocity between 70 and 40 m/sec., and whose action potential was maximal at the threshold value

for the negative potential. On the other hand on excitation of coarse cutaneous afferents, the threshold for the negative cord potential was approximately the same as that for the afferent spike of these fibres, and the cord potential reached its maximum when the amplitude of the afferent spike was still only 70 per cent of its maximal value (BERNHARD, 1953). Thus, it is not until the smaller splanchnic nerve fibres are excitated that the slow dorsal cord negativity appears. Experiments in which the afferent volley in the sympathetic trunk was recorded with higher amplification than in Fig. 10 have shown that the negative cord potential appeared at a stimulus strength that activated the delta fibres of the splanchnic nerve, the fastest of which had a conduction velocity of about 20 m/sec.

The threshold value, latency (see Fig. 14) and duration of this negative potential are also in fairly good agreement with those of the negative cord potential which BERNHARD observed in response to stimulation of high threshold muscle afferent fibres (Group III fibres).

Comment to section V. As mentioned above, stimulation of the A beta fibres in the splanchnic nerve evoked no discharge in the intercostal or lumbar nerves nor any sign of reflex action in the animal. Neither was any viscero-enteric reflex observed. Thus it may be assumed that there is no anatomical basis for such spinal reflexes, i. e. that the coarse afferent splanchnic nerve fibres, in contrast to the coarse cutaneous afferent nerve fibres, send no collaterals to the dorsal horn cells in the spinal cord. However, it is of course possible that there are such collaterals which pass to the dorsal horn and synapse on neurones whose axons then run in one of the ascending fibre systems in the lateral columns. According to BOHM (1953) the anterolateral fibre system connected with coarse cutaneous afferents is a spino-bulbo-cerebellar system. If the coarse afferent splanchnic nerve fibres actually were connected with the neurones which travel with the fibres in this system, the fact that they do not project to the cerebellum would be still more remarkable, especially since their projection to the cerebral cortex does not essentially differ from that of coarse cutaneous nerves.

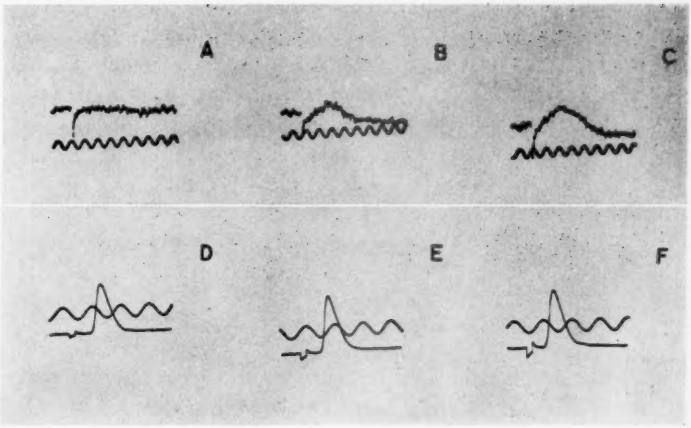

Fig. 10. A—C, the action potential recorded from the cord dorsum at Th 11, and D—F, the afferent volley in the sympathetic trunk, in response to stimulation of the left splanchnic nerve. Conduction distance in D, E and F was 5.5 cm. The relative stimulus strength was in A and D, 1; in B and E, 2; in C and F, 3. The stimulus strength just liminal for the spinal cord potential (B) was supramaximal for the spike potential of large fibres recorded in the sympathetic trunk (E). Time: A—C, 100 c/s; D—F, 1000 c/s.

The results of the experiments on the spinal cord potentials described above would seem to shed some light on this question. The action potentials which can be obtained in leads from the dorsum of the cord following stimulation of various cutaneous and muscle afferents have recently been thoroughly analysed by BERNHARD and co-workers.

The large negative deflection—BERNHARD'S "N_1 deflection"—obtained with stimulation of coarse cutaneous afferents is generated, according to BERNHARD (1953), in postsynaptic structures. These structures do not necessarily participate in multisynaptic reflex transmission (BERNHARD and WIDÉN, 1953), and therefore part of the N_1 deflection may be the expression of activity of neurones in transsynaptic spino-bulbar transmission systems. Stimulation of the splanchnic A beta fibres produced no spinal reflex discharge. Consequently, the occurrence of an N_1 deflection would have been interpreted as a sign of activity in structures which transmit the afferent impulses to higher centres. As shown

in Fig. 10, stimulation of these coarse fibres produced, however, no slow potential in leads from the dorsum of the cord. The results of these experiments do not, of course, exclude the possibility that the coarse afferent splanchnic fibres send collaterals to the grey matter of the dorsal horn, though also other experimental results (lack of spinal reflex responses as well as of cerebellar responses to stimulation of the coarse fibres) give no evidence of this.

VI. Spinal Pathways of the Splanchnic Cerebellar Projection System.

In order to map the spinal pathways of the cerebellar impulses of splanchnic nerve origin, experiments were performed in which different parts of the spinal cord were transected while recording the splanchnic cerebellar responses. Fig. 11 illustrates one of these experiments. Record A shows the response from the contralateral paramedian lobule following stimulation of the left splanchnic nerve, and record C the response from the anterior lobe. Transection of the contralateral half of the spinal cord at the level of C 4 abolished the response from the contralateral paramedian lobule (B) whereas the response from the anterior lobe remained unchanged (D). Transection of the ipsilateral dorsal column at the level of C 3 (E) as well as further section of the entire ipsilateral dorsal quadrant of the spinal cord at the same level left the response unchanged (F). It was controlled that also the response in the ipsilateral paramedian lobule remained unaffected by these transections. The extent of the lesions to the spinal cord was confirmed histologically and is shown in the drawings in Fig. 11 made with the aid of a projection apparatus.

Thus the experiment shows that the afferent impulses from the splanchnic nerve reach the cerebellum via fibres ascending in the anterior quadrant of the spinal cord and that the fibres which convey impulses to the contralateral paramedian lobule decussate in the spinal cord. It therefore follows that responses in this "area III" are not secondary to responses in the anterior lobe or ipsilateral paramedian lobule, a possibility that has been discussed earlier (BRODAL 1953).

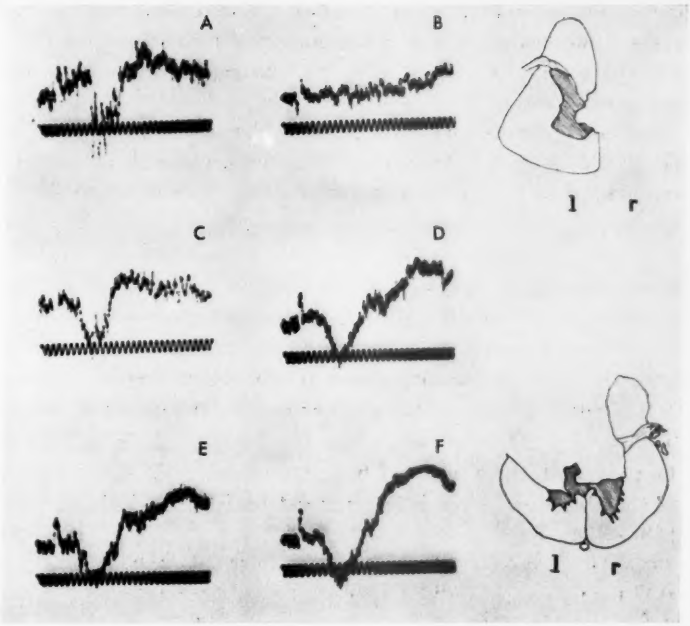

Fig. 11. Responses obtained in the right paramedian lobule (A) and the left posterior part of culmen (C) to stimulation of the left splanchnic nerve. Section of the right half of the cord at C 4 abolished the response in the right paramedian lobule (B) while the response in culmen was practically unaltered (D). The response in culmen was not modified by transection of the ipsilateral dorsal column (E) or by section of the ipsilateral dorsal quadrant at C 3 (F). Time: 250 c/s. The extent of the lesion at C 4 is shown in the upper drawing and at C 3 in the lower drawing.

No detailed studies were made of the supraspinal pathways of the afferent impulses from the splanchnic nerve to the cerebellum. The fact that evoked cerebellar potentials could be obtained following splanchnic nerve stimulation also on acute decerebrate preparations, in which the brachia conjunctiva are easily damaged if section is made at the level of the posterior corpora quadrigemina, made it *à priori* less probable that the impulses were transmitted via the superior cerebellar peduncles. Since the spinopontine tracts are considered not to be the projection pathway for the splanchnic afferent impulses to the cerebellum (See Dis-

cussion) it seemed likely that the responses were transmitted over the restiform bodies and attempts were made to record the afferent volley from them. Fig. 12 illustrates one of these experiments.

A fine steel needle electrode, insulated except for the tip, was inserted into the restiform body following aspiration of the posterior parts of the cerebellum. Record B shows the action potential of the afferent volley in the ipsilateral, and C in the contralateral, restiform bodies following stimulation of the left splanchnic nerve. The latency for the two responses was about the same, approximately 17 msec. (calculated on records taken at higher sweep speed than those shown in Fig. 12). Record A from the same preparation shows the cerebellar response evoked in the third folium of culmen anterior to the primary fissure. The latency to the response was 19—20 msec. It is of interest to note that there was no distinct difference in the latencies of the responses in the ipsilateral and contralateral inferior cerebellar peduncles.

Bohm has recently shown that the afferent inflow from low threshold cutaneous fibres into the three receiving areas in the cerebellar cortex is transmitted by fibres ascending in the anterolateral columns of the spinal cord. On the other hand, the impulses from coarse cutaneous afferents to sensory areas I and II in the cerebral cortex are transmitted via the dorsal columns. Conditions appear to be analogous with regard to the splanchnic nerve projection; AMASSIAN (1951 b) and DOWNMAN (1951) have shown that the splanchnic afferent inflow into sensory areas I and II of the cerebral cortex is transmitted via the dorsal columns, while our experiments indicate that the impulses to the cerebellum are transmitted via fibres in the anterior quadrant.

VII. Interaction between Responses Evoked from Somatic and Visceral Afferents

Since the present experiments showed that the splanchnic cerebellar projection area in the anterior lobe overlaps that of the tactile sensory system, it was considered of interest to in-

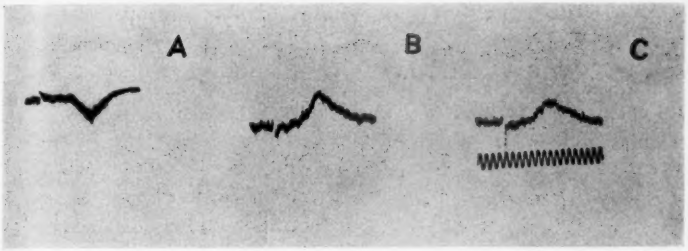

Fig. 12. Responses obtained with stimulation of the left splanchnic nerve. A, in the ipsilateral posterior part of culmen. B, in the ipsilateral, and C, in the contralateral, inferior cerebellar peduncles. B and C recorded with needle electrodes. Time: 250 c/s.

vestigate whether any interaction could be demonstrated between the cerebellar responses evoked from somatic sensory afferents and those evoked from visceral afferents within the thoracolumbar division of the autonomic system. Fig. 13 shows the results of one of these experiments. Record A shows the response in the ipsilateral posterior part of culmen evoked by shock stimulation of the left splanchnic nerve. Record B shows the response in the same area after stimulation of the 12th intercostal nerve on the left side. In record C the two responses were superimposed by stimulating the two nerves simultanously. The resultant response was of slightly shorter duration and had an amplitude which only slightly exceeded that of the response to stimulation of the individual nerves. Thus the experiment shows a high degree of occlusion of the two afferent volleys. However, no conclusion can be drawn with regard to the initial site of the interaction, i. e. whether the neuronal convergence is a cortical or subcortical event. Since the experiment was performed on a decerebrate preparation no supracollicular structures can have been involved.

Record D shows the cerebellar response to a test shock to the left splanchnic nerve. In record E this shock was preceded by a subliminal stimulus to the ipsilateral 12th intercostal nerve. The shock interval was about 45 msec. (because of the low strength of the conditioning stimulus no shock artefact is seen in the figure). The test response was now only a small, insignificant deflection. Thus the subliminal conditioning stimulus to the inter-

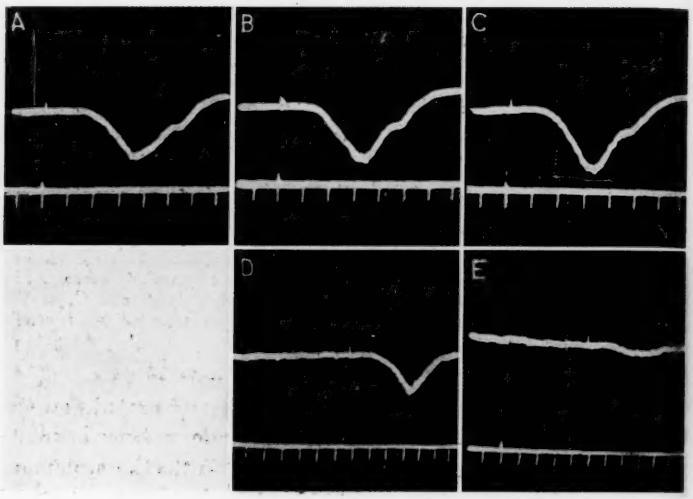

Fig. 13. Responses obtained in the ipsilateral posterior part of culmen to stimulation of the left splanchnic nerve (A) and the left 12th intercostal nerve (B). C shows the compound response obtained by stimulation of the two nerves at about zero interval. D shows the cerebellar test response to stimulation of the splanchnic nerve, and E the same response modified by an antecedent subliminal conditioning shock to the intercostal nerve. Stimulus interval about 45 msec. The moment of the conditioning shock is marked on the time scale. Time marker: 10 msec.

costal nerve caused definite inhibition of the splanchnic test response. Since the conditioning stimulus in this case did not evoke the slightest positive deflection in leads from the cerebellar cortex, it appears highly probable that the blocking interaction occurred at a subcortical level, i. e. in the spinal cord or in the medulla oblongata.

Some experiments were performed to test the validity of the above assumption that a blocking interaction between impulses from the splanchnic and intercostal nerves may take place at a spinal level.

The slow dorsal cord negativity evoked by stimulation of coarse cutaneous afferents, i. e. the N_1 potential, is considered to signal the activity in postsynaptic structures which partly are engaged in reflex transmission at the spinal level and partly convey as-

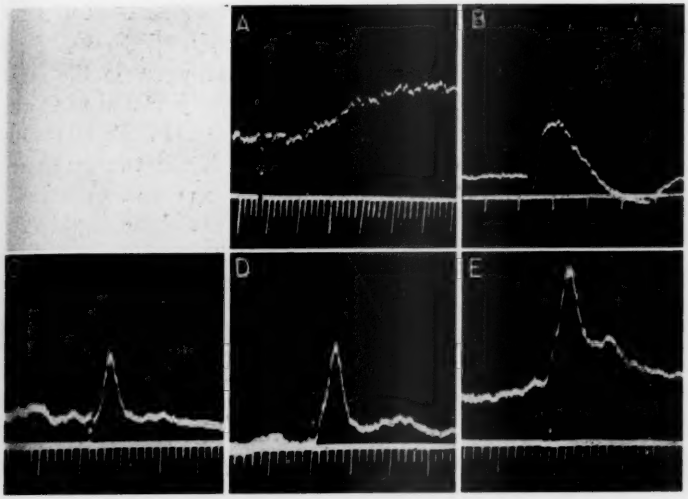

Fig. 14. The action potential recorded from the cord dorsum at Th 9 following stimulation of the left splanchnic nerve (A), and at Th 12 following stimulation of the left 12th intercostal nerve (B). E shows superimposed the cord potentials obtained with stimulation of the splanchnic nerve (C) and the 9th intercostal nerve (D) at an interval of about 10 msec. to permit synchronization of the maximum points of the two negativities. Time markers: in A, 1 msec.; in B—E, 10 msec.

cending impulses to suprasegmental levels, probably via the anterolateral spino-bulbar fibre system. Also the slow negative potential elicited by stimulation of delta fibres has been shown to be generated in postsynaptic structures (BERNHARD, 1953). It was therefore considered to be of interest to use the dorsal cord potentials as index in conditioning experiments. Fig. 14 illustrates one of these experiments.

Record A, taken at fairly high sweep speed, shows the initial phase of the negative cord potential at the level of Th 9 in response to stimulation of the splanchnic nerve. The latency was 5—6 msec. The rising phase was rather slow, the maximum negativity being reached only after 25 msec. Record B shows the cord dorsum response at the level of Th 11—Th 12 evoked by stimulation of the 12th intercostal nerve. The short latency and sharply rising phase of the negative potential are clearly shown,

characteristics which it has in common with BERNHARD'S N_1 wave.

Records C to E show a conditioning experiment on the same preparation as in record A. The slow negative potential in C was evoked by stimulation of the splanchnic nerve and in D, by stimulation of the intercostal nerve. In record E the two responses were superimposed by stimulating the two nerves at an interval of about 10 msec., so that the maximum points of the negativities coincided. Record E shows that the amplitude of the total response was approximately 70 per cent of that obtained when the amplitudes of the responses evoked from the intercostal nerve and the splanchnic nerve are added together. Thus there was a high degree of occlusion. Since occlusion is generally considered to be a sign of neuronal sharing, it may be concluded that impulses from the afferent delta fibres of the splanchnic nerve and from the afferent fibres of the intercostal nerve to some extent converge on the same postsynaptic structures. If it is true that part of these structures belong to a spino-bulbo-cerebellar system some of the blocking interaction between the cerebellar responses from the two afferent sources may be explained by this occlusion at the spinal level.

Comment to Section VII. BREMER and BONNET (1951) and BREMER (1952) studied the interaction between cerebellopetal volleys from various types of afferent nerves but made no attempt to determine the site of interaction. Fig. 13, E, which shows inhibition of the test response after a conditioning stimulus that is subliminal for the cerebellar response, indicates that a neuronal convergence of the projection systems for splanchnic visceral afferents and somatic afferents occurs at a subcortical level. This conclusion seems justified regardless of whether, in conformity with BREMER (1952), one interprets the initial positive deflection as caused by the action potential of the afferent volley when it reaches the cortex as well as by action potentials in the cerebellar interneuronal axons or, in conformity with ECCLES' (1951) theory on the primary positivity in the cerebral cortex, as caused by the synaptic potentials in the soma and dendrites of the cells which are activated by the afferent volley.

AMASSIAN (1952) made an electrophysiological study of interaction in the somato-visceral projection system, with especial reference to the sites of interaction. He found a high degree of occlusion at the level of the thalamus and drew the conclusion that thalamic interaction may be more important than interaction in the spinal cord. He points out that this does not agree with the majority of theories on reference of visceral pain according to which the point of interaction is in the spinal cord. The central interaction experiments performed by him were, however, concerned solely with fibres ascending in the posterior columns and therefore his conclusions cannot, as he himself points out, be applied to the pain system. Fig. 14, on the other hand, showed that a not insignificant blocking interaction between the afferent inflows from splanchnic delta fibres and cutaneous fibres takes place already at a spinal level.

The intercostal nerve used in these experiments was a mixed nerve. No attempt was made to determine which fibre group of the nerve was responsible for the evoked cerebellar potentials. As MOUNTCASTLE and co-workers (1952) have shown, stimulation of Group I and II muscle afferent nerves yields scarcely any significant cerebellar responses in anaesthetized preparations and only very small responses in unanaesthetized animals. Neither does stimulation of these fibre groups in muscle nerves give rise to spinal cord potentials of the type seen in Fig. 14, B. It is therefore probable that both the cerebellar response and the spinal cord potential are the result of activation of cutaneous afferents and, possibly, Group III muscle afferent nerves.

B. CEREBELLAR PROJECTION OF HIGH THRESHOLD FIBRES IN SOMATIC AFFERENTS

Since the experimental results in the present investigation indicate that the afferent impulses from the splanchnic nerve to the cerebellum are mediated by a group of high threshold slowly conducting fibres and, possibly, are of nociceptive type, it was considered to be of interest to investigate whether the small myelinated fibres belonging to other sensory systems likewise possess a cerebellar representation.

I. Facial Nerve

Various peripheral branches of the facial nerve were selected for this purpose, since they are said to contain exclusively fibres of small size: 1 to 6 μ in diameter (BRUESCH, 1944). It was believed that by utilizing these fibres it might be possible to study the central connections of small afferent fibres without needing to resort to a method for blocking the coarse fibres.

Just after its emergence from the stylomastoid foramen the facial nerve gives off the posterior auricular nerve, and subsequently divides into a dorsal and a ventral ramus. The dorsal ramus subsequently divides into the zygomatic and temporal nerves, the former proceeding to the caudal angle of the eye and the latter distributing itself in the musculature lying craniad of the external ear. The ventral ramus divides to form the superior and inferior buccal nerves of which the former innervates the musculature of the upper lip and also anastomoses with the temporal branch of the auriculotemporal nerve from the trigeminal nerve, and the latter innervates the musculature of the lower lip (TAYLOR and WEBER, 1951). The present investigations on the dorsal and ventral rami of the facial nerve as well the posterior auricular nerve produced essentially similar results.

Fig. 15 illustrates an experiment on an anaesthetized cat in which the cerebellar response was evoked by stimulation of the posterior auricular nerve on the left side. The response was

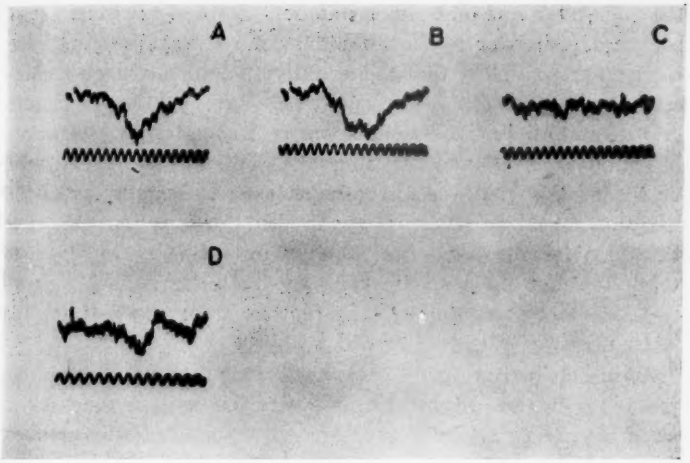

Fig. 15. The response in the ipsilateral posterior part of culmen to stimulation of the left posterior auricular nerve before (A) and after (B) intracranial section of the trigeminal nerve. Section of the vagus nerve at the jugular foramen abolished the response (C). D shows the response in the same area to stimulation of the left superficial radial nerve. Time: A—C, 250 c/s; D, 500 c/s.

recorded from the most posterior folium of culmen slightly to the left of the midline. Record A shows the response before, and B the response after, section of the trigeminal nerve. All the branches of this nerve were divided in the medial cranial fossa immediately distal to the gasserian ganglion. As shown in record B, this operative procedure had no effect on the cerebellar response.

It is well established that the vagus nerve gives off an auricular branch for distribution to the external ear. This branch is considered to be a purely general somatic sensory nerve. It leaves the stylomastoid foramen together with the facial nerve (TAYLOR and WEBER, 1951). Its perikarya lie in the jugular ganglion. To ascertain whether the posterior auricular afferent fibres which project to the cerebellum enter the brain stem together with the vagus nerve, the latter was sectioned intracranially at the jugular foramen. Record C shows that section of the vagus nerve abolished the cerebellar response. In other experiments it was shown with

the same technique that also the afferent fibres of the other facial branches, projecting to the cerebellum, are of vagal origin. Since there was a possibility that the operative procedure, which technically was not altogether easy, might have damaged the cerebellum or its connections, its function was regularly tested afterwards by stimulation of another afferent nerve. In the experiment illustrated in Fig. 15 the cerebellar response to stimulation of the left superficial radial nerve was studied for this purpose. The threshold for the cerebellar response from this nerve was one tenth that for the response from the posterior auricular nerve and its latency was shorter than that for the response from the latter nerve.

According to BRUESCH (1944) the afferent vagus fibres which proceed with the peripheral branches of the facial nerve vary in size from 1 to 20 μ. The coarse fibres, however, are few in number. Fig. 16 illustrates an experiment to determine which fibre group is responsible for the cerebellar response. Records A and B show the action potentials recorded from the most posterior folium of culmen in response to stimulation of the dorsal ramus of the left facial nerve following intracranial section of the trigeminal nerve. Records C and D show the action potentials recorded from the stimulated nerve at a point 2.4 cm. distal to the stimulating electrodes. The poles of the stimulating electrodes were reversed so that the cathode was between the anode and the recording electrodes when recording both from the cerebellum and the peripheral nerve. The stimulus strength in A and C was half the threshold value for the cerebellar response, and in B and D three times the threshold value, and then submaximal for the cerebellar response. A comparison of records C and D shows that the action potential of the coarse fibres in the stimulated branch of the facial nerve had reached its maximum at a stimulus strength that was half the threshold value for the cerebellar response. Therefore, it is reasonable to conclude that the latter was not the product of impulses mediated by coarse fibres. The shortness of the conduction distance in this experiment did not permit further analysis of the conduction velocities of the afferent fibres involved.

Experiments were performed in which the respiratory and

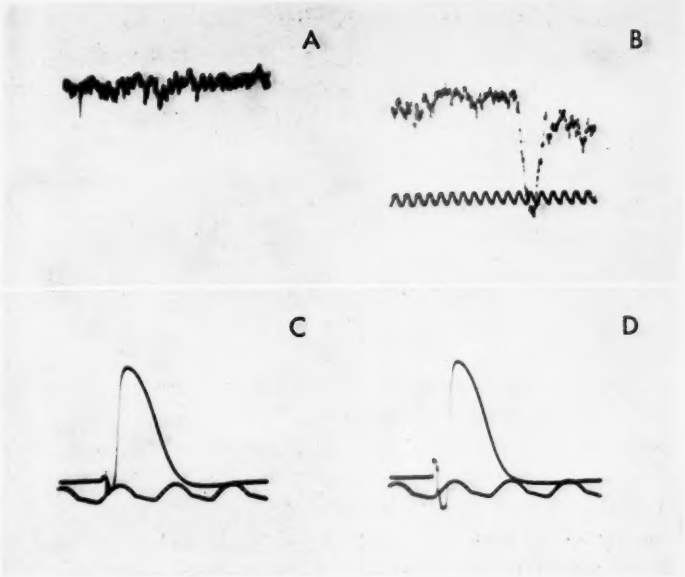

Fig. 16. Responses obtained with stimulation of the dorsal ramus of the facial nerve in the ipsilateral posterior part of culmen (A and B) and at a point on the nerve 2.4 cm. distal to the stimulating electrodes (C and D). The stimulus strength in B and D was 6 times that in A and C. Time: A and B, 500 c/s; C and D, 1000 c/s.

arterial blood pressure reactions were recorded on a kymograph and the pupillodilator response was observed under a steady light during stimulation of various branches of the facial nerve. It was observed that during stimulation the respiratory movements increased in frequency, often with a concomitant diminution of the magnitude. Dilatation of the pupil occurred within a few seconds of commencement of stimulation. The effect on the blood pressure was more complicated; there was an initial lowering of short duration, followed by an increase of about the same magnitude. A closer analysis of this effect was not done in the present investigation. The threshold for these reactions of the pupil, respiration and blood pressure was the same as that for the cerebellar response.

II. Cutaneous Nerves

Experiments were also performed to ascertain whether it was possible to elicit cerebellar responses by stimulation of delta fibres in somatic afferents from the skin. To elucidate this it was necessary to block impulse transmission in the coarse cutaneous fibres while recording the afferent volley in the nerve proximal to the block to control the effect of the block. This was achieved by so arranging the stimulating electrodes that the anode was between the cathode and the recording electrodes on the nerve and increasing the stimulus strength (shock duration about 2 msec.) so that impulse transmission in the large fibres was blocked at the anode. The threshold for anode block is dependent on internodal length, the small fibres having a higher threshold for block. Therefore it is possible to use a stimulus strength which permits only the impulses in the small fibres to be transmitted past the anode.[1] KUFFLER and VAUGHAN WILLIAMS (1953) have used a technique somewhat similar to ours for selective stimulation of high threshold fibres. Their technique however was based on the difference in the conduction velocities of the large and small fibres, while our technique was based on the difference in the thresholds for anode block.

In the experiment illustrated in Fig. 17, A and B, the proximal cut end of the superficial radial nerve was placed on the stimulating electrodes, with the cathode proximal. The action potential of the nerve was recorded at a point 8.0 cm. proximal to the stimulating electrodes (A). The response consisted of two elevations, the second of which corresponded to a maximal conduction velocity of 23—22 m/sec. In record B the upper tracing shows the cerebellar response evoked by the afferent volley, and the lower tracing the afferent volley recorded at an amplification three times that used in record A.

Record C shows the afferent volley response recorded from the same point on the nerve as in A, but with the poles of the stimulating electrodes reversed, so that the anode was proximal. The conduction distance from the cathode was about 9.0 cm. The two

[1] I am indebted to Dr. B. FRANKENHAEUSER for indicating the advantage of this method for selective activation of small fibres.

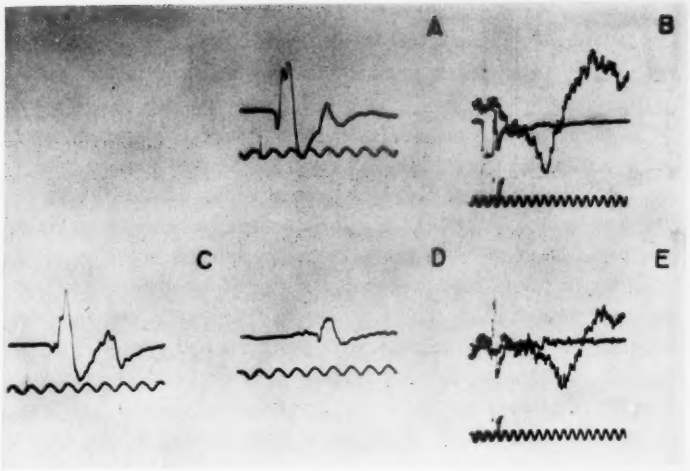

Fig. 17. Action potential of the afferent volley in the left superficial radial nerve (A, and lower tracing in B) and the cerebellar response (upper tracing in B) evoked by stimulation of the proximal cut end of the nerve, with the cathode proximal.
The afferent volley (C, D, and lower tracing in E) and the cerebellar response (upper tracing in E) evoked by stimulation of the same nerve with the anode proximal. The stimulus strength was in C, one half, and in D and E, the same as, that in A and B. Time: A, C, D, 1000 c/s.; B and E, 500 c/s.

elevations seen in the record correspond to the same conduction velocities as those seen in record A. The stimulus strength in C was half that in A. At the stimulus strength used in A, the first elevation was practically abolished (D), and only the second elevation, which signals the activity of fibres with a maximal conduction velocity of 23—22 m/sec. persisted. Thus, the impulses in fibres with higher conduction velocities were blocked at the anode. It was checked that the stimulus strength required for anode break excitation was higher than that used in record D and that the action potential in record D was not the result of anode break excitation.

Record E (upper tracing) shows the cerebellar response evoked by the afferent volley in D. Accordingly, this is the response to activation of high threshold cutaneous afferents (delta fibres) in isolation. It will be seen that the latency to the cerebellar response

in E was longer than that in B. The difference was about 6 msec. The lower tracing shows the action potential of the afferent volley recorded at an amplification three times that used in D.

Comment to Section VIII. The results of these experiments indicate that afferent fibres of vagal origin are present also in peripheral branches of the facial nerve other than those to the region of the ear, and that they possess a cerebellar representation. The presence of afferent fibres in the peripheral branches of the facial nerve of cat was earlier demonstrated by BRUESCH (1944) in anatomical studies. The fibres were few in number and were derived partly from the geniculate ganglion and partly from the vagus nerve. In the present investigation no cerebellar response or reflex discharge to the facial musculature could be obtained with stimulation of any of the facial nerve branches, not even of the auricular nerve, after intracranial section of both the trigeminal and vagal nerves. Thus the existence of afferent fibres of geniculate ganglion origin could not be demonstrated.

The finding that the cerebellar response to stimulation of the facial nerve is mediated by high threshold afferent fibres and that the stimulus threshold for the response is the same as that for eliciting nociceptive reactions suggests that the afferent fibres may be of nociceptive type. BRUESCH has presented anatomical evidence which also indicates that the majority of the afferent fibres in the facial nerve branches are concerned with the conduction of pain impulses.

Some investigations on man support the view that the vagus nerve may mediate pain impulses from the head. Stimulation of the intracranial portion of the nerve resulted in pain behind the ear and in the back of the head (WOLFF, 1948). FAY (1932) studied a group of patients with "atypical facial neuralgia" and concluded that the pain originated in the external carotid artery and its maxillary branches and was transmitted by branches given off by the vagus nerve. Pain about the ear, e. g. that due to herpes zoster, however, has commonly been ascribed to affection of afferent fibres arising in the geniculate ganglion, so-called "geniculate neuralgia" (HUNT, 1937), but conclusive data are lacking.

The experiments with anode block of impulse transmission in

the large afferent fibres of a cutaneous nerve (Fig. 17) have clearly demonstrated that the delta fibres of cutaneous nerves possess a cerebellar representation. The above-mentioned results of earlier investigators indicate that pain, the so-called first pain, is mediated by fibres belonging to this group.

It is interesting to note that the magnitude of the cerebellar response obtained with stimulation of the delta fibres in cutaneous nerves is very similar to that obtained with stimulation of the coarse fibres.

The experiment illustrated in Fig. 17 also provides interesting information concerning the relationship between the size of the primary afferent fibres and the conduction velocity of the spinal neurones transmitting their impulses. The difference in the latencies of the cerebellar responses to stimulation of the coarse afferent fibres and the delta fibres was 6 msec. The conduction distance along the nerve was 20 cm. The conduction velocity of the coarse fibres was 66 m/sec. (A and C), and that of the delta fibres 23 m/sec. (A, C, D). Thus the impulses mediated by the delta fibres reached the spinal cord about 6 msec. later than those mediated by the fastest conducting fibres. Hence the difference in the latencies of the cerebellar responses to stimulation of the two fibre groups studied here may be explained by the difference in the conduction velocities of the primary afferent neurones. Consequently, there can be no difference in the conduction velocities of the spinal neurones transmitting the impulses from the respective primary afferents. The possibility exists, of course, that the fast and slow afferent fibres terminate on the same postsynaptic neurones.

DISCUSSION

For mapping the cerebellar projection areas of the splanchnic afferent fibres in the present study cerebellar responses with a latency of 18—22 msec. to the initial positive phase were used as index in the anterior lobe.

The use of the initial positive phase of the cerebellar response, regardless of its latency, as index in electrophysiological mapping studies has been criticized by CARREA and GRUNDFEST (1954). These authors, who studied the cerebellar projection of various deep and superficial nerves via the ventral spinocerebellar tract, demonstrated cerebellar responses with considerably shorter latency and more circumscribed areas of projection than those found by other authors with electrical stimulation of peripheral nerves.

Similar early responses mediated by the dorsal spinocerebellar tract were demonstrated by GRUNDFEST and CAMPBELL in 1942. They were also observed by COMBS (1954), though only in decerebrate unanaesthetized preparations. In the present investigation they were recorded also in lightly anaesthetized preparations following stimulation of the superficial radial nerve (Fig. 1, G and K). Responses with such a short latency were not, however, observed following stimulation of the splanchnic nerve.

The initial positive potential with longer latency commonly observed in anaesthetized preparations is considered by CARREA and GRUNDFEST to be the product of intracerebellar activity which is not specifically related to any single afferent inflow and therefore cannot be used as an index of primary distribution of afferents to the granular layer of the cerebellum. COMBS, however, states that even if part of this so-called initial positive potential represents activity of cerebellar components other than afferent fibres "it would not significantly alter electro-anatomical mapping studies since the primary concern is to determine the cerebellar areas influenced by afferent fibre stimulation regardless of precisely how this effect is exerted." It seems probable that the features of the evoked cerebellar response are dependent on which spinal

pathway the afferent impulses utilize. Further knowledge on this point is desirable.

While the existence of somatotopic localization in the cerebellum is certainly of great interest, this knowledge cannot furnish further information so long as the functions of the various parts of the cerebellum, e. g. the projection areas most studied: anterior lobe, lobulus simplex, vermis and paramedian lobules, remain practically unknown. A strictly functional localization of the afferent impulses does not seem to exist. It has been unequivocally shown that some sensory systems project to areas in which, on the anaesthetized preparation, the other systems hitherto investigated are little, if at all, represented, but there exists considerable overlapping and the projection areas for different sensory modalities would seem to some extent identical.

As mentioned in the introduction, earlier investigations have shown that the projection areas for muscle afferents coincide with those for cutaneous nerves. Likewise, the representation for the vagus, olfactory and trigeminal nerves in the posterior parts of the anterior lobe are to some extent identical. The present investigations have shown that also impulses from afferent delta fibres in the splanchnic nerve, which may possibly transmit nociceptive impulses from the viscera, project to the last-mentioned area and appear to have their maximum within the projection area for tactile impulses from the trunk, as described by SNIDER and STOWELL. This is in conformity with the fact that electrical stimulation of intercostal nerves evokes potentials within this area. Also within the paramedian lobules the area for the responses evoked from the splanchnic delta fibres overlaps the projection areas for tactile and olfactory impulses. COMBS recorded no evoked responses in the paramedian lobules or any portion of the vermis outside the anterior lobe on electrical stimulation of various thoracic roots even in unanaesthetized preparations. In the present investigation, however, stimulation both of the splanchnic nerve and of the lower intercostal nerves evoked responses in the ipsilateral and contralateral paramedian lobules.

The investigations of AMASSIAN (1950, 1951 b) and DOWNMAN (1951) have shown that the afferent inflow from the splanchnic nerve to sensory areas I and II in the cerebral cortex travels in

the dorsal columns. In the present investigation transection of the dorsal columns as well as the dorsal half of the spinal cord had no effect on the cerebellar responses evoked from the splanchnic nerve. Furthermore, it was found that the spinal pathway to the splanchnic cerebellar projection area in the anterior lobe as well as in the ipsilateral paramedian lobule is uncrossed while the fibres giving rise to the responses in the contralateral paramedian lobule decussate in the spinal cord. By recording with needle electrodes from the restiform bodies it was shown that the afferent impulses from the splanchnic nerve to the cerebellum are conveyed via these cerebellar peduncles. A direct spinocerebellar tract other than the classical pathways of FLECHSIG and GOWERS is not known. Of these, the former cannot come into question here since it runs in the dorsal quadrant of the spinal cord and, moreover, most probably mediates impulses exclusively from muscle nerves (GRUNDFEST and CAMPBELL, 1942; LLOYD and MCINTYRE, 1950). GOWER'S tract, on the other hand, proceeds via the brachium conjunctivum, ascends in the anterolateral column of the spinal cord, mainly on the side contralateral to the primary afferents (this applies at least to the lumbar segment; see CARREA and GRUNDFEST) and any projection to the paramedian lobules has not been described. These factors make it improbable that the splanchnic cerebellar impulses are conveyed by this tract, though the possibility of a splanchnic nerve projection to the anterior lobe via this tract has not been excluded.

Consequently, it may be assumed that the afferent impulses from the splanchnic nerve have, in addition to the relay in the dorsal horn of the spinal cord, a synaptic relay in a nucleus at a higher level. The fibre systems which can then come into question are the spino-olivo-cerebellar, the spino-ponto-cerebellar and the spino-lateral reticular nucleus-cerebellar. The first apparently consists of two systems: a dorsal spino-olivary tract (GRUNDFEST and CARTER, 1954) which proceeds contiguous with the dorsal spinocerebellar tract and therefore is out of the question, and a ventral which runs in the ventral and ventrolateral parts of the spinal cord (BRODAL, WAHLBERG and BLACKSTAD, 1950) to which somewhat more than half of the fibres come from the contralateral dorsal horn and the remainder from the ipsilateral.

From the inferior olive fibres proceed, as is known, via the internal arcuate fibres and restiform bodies to the contralateral half of the cerebellum. Those parts of the olive which, according to BRODAL and co-workers, receive spinal fibres (i. e. parts of the dorsal and medial accessory olive) send no fibres to the paramedian lobules (BRODAL, 1940). Therefore, this system cannot be the primary projection system for the splanchnic cerebellar impulses. Neither do the evoked responses in the ipsilateral anterior lobe seem to be to any great extent conducted via this system because, if they were, they would diminish or disappear on transection of the contralateral half of the spinal cord.

The ascending fibres of the spino-ponto-cerebellar system intermingle with the descending fibres of the lateral and ventral cortico-spinal tracts (WAHLBERG and BRODAL, 1953). Consequently, the majority of them would seem to have been transected in the experiments with lesion of the dorsal quadrants of the spinal cord. According to BRODAL and JANSEN (1946), the spinal impulses relayed via the pons to the cerebellum influence predominantly the cerebellar hemispheres and to some extent the paraflocculus, thus areas entirely different from those in which responses of splanchnic origin were recorded.

There remains, then, only the spino-lateral reticular nucleus-cerebellar system. According to BRODAL (1949, 1953) this is the only one of the known fibre systems which, from the neuroanatomical point of view, is so organized that it can be assumed to conduct the tactile impulses which project to somatotopically organized areas in the cerebellum. This concept has received further support from the experimental evidence presented by BERRY and co-workers (1950) and BOHM (1953). Thus there would seem to exist a close parallelism between the projection systems of the cutaneous nerves and the splanchnic visceral afferents to the cerebellar cortex.

The threshold for the cerebellar response to splanchnic nerve stimulation has been shown to be the same as that for activation of afferent fibres with conduction velocities ranging from 24 m/sec. to about 15 m/sec. The conduction velocity in the spinal pathways was not studied in the present investigations. The latency to the cerebellar response in area I varied between 18

and 22 msec. AIDAR and co-workers (1952), who analysed the splanchnic afferent pathway in the spinal cord, found impulses with a velocity of 15—9 m/sec. running in the anterolateral parts of medulla. This value does not agree with the latencies to the cerebellar responses on stimulation of the splanchnic nerve found in the present study. Even taking into account the fact that the impulses may ascend in the sympathetic trunk to the level of Th 6 or Th 5 (RANSON and BILLINGSLEY, 1918) at a velocity of 24—20 m/sec., this still leaves a conduction distance of about 22 cm. which, at a conduction velocity of 15 m/sec., would require 30 msec. AIDAR and co-workers recorded the ascending impulses in the anterolateral columns with a concentric needle electrode in the cervical spinal cord after stimulation of the splanchnic nerve; they do not appear to have made any allowance for synaptic delay in the dorsal horn. These authors further stated that "the recording electrodes were capable of extremely close localization" and therefore "failure to record activity in a specific region, even in a large series of animals, cannot be considered conclusive."

No definite statement can be made concerning the sensory modalities of the impulses transmitted by the splanchnic nerve to the cerebellum. It is now generally agreed that the viscera are sensitive to pain (GERNANDT and ZOTTERMAN, 1946; and others). A number of observations also on man (WHITE et al., 1952; BONICA, 1953) have shown that the abdominal viscera are pain sensitive and that their sensory axons run with the sympathetic nerves, primarily in the splanchnic nerve. After unilateral section of the splanchnic nerve, the pain of duodenal distension was no longer perceived on the operated side and after bilateral splanchnicectomy, distension caused no pain on either side (BENTLEY and SMITHWICK, 1940). Electrical stimulation of the splanchnic nerve during the course of operation under local anaesthesia (ARNULF, 1948; WHITE and SWEET, 1952) produced severe pain and ARNULF stated that the splanchnic nerve seems to be "un nerf d'une extreme sensibilité à la douleur." That the vagus does not convey pain fibres below the diaphragm has been shown by CANNON (1933) in experiments on fully conscious cats with implanted stimulating electrodes.

It is therefore obvious that the splanchnic nerve contains

afferent pain conducting fibres of which the myelinated would be expected to have the same stimulus threshold and conduction velocity as those from which the cerebellar responses can be evoked. Thus there exists a possibility that the impulses from the splanchnic nerve to the cerebellum are of nociceptive type. In the present investigation it was further shown that the cerebellar response to splanchnic nerve stimulation has the same threshold as certain reflex responses which in earlier investigations have been regarded as nociceptive reactions, namely, reflex contraction of the trunk muscles, arterial blood pressure increase and pupillary dilatation.

It might be thought remarkable that the coarse afferent splanchnic fibres have no cerebellar projection. In the present study at any rate no cerebellar responses could be demonstrated in those parts of the cerebellar cortex which were explored (posterior folia of culmen, lobulus simplex, vermis, paramedian lobules and the most medial parts of crus I and II). It might be argued that these relatively few fibres may give rise to potential changes which are so small that they may be over-looked or are possibly so sensitive to anaesthesia that they cannot be demonstrated in anaesthetized preparations, as in the case of cerebellar responses evoked from large muscle afferents (MOUNTCASTLE et al., 1952). This, however, would seem to be less probable in view of the large responses which stimulation of the coarse splanchnic nerve fibres evokes in the cerebral cortex and which have an amplitude of 100—200 microvolts. According to SNIDER (1950) the cerebellum functions "in some manner to coordinate muscular movements as a result of a cerebral 'decision'" and therefore it seems less remarkable that the splanchnic nerve beta fibres lack cerebellar representation since the impulses conveyed by these fibres have not been shown to evoke any demonstrable reflex action, at least no muscle reflex response, either in this investigation or that of earlier workers.

As SNIDER, however, emphasized, the function of the cerebellum is probably greater than that of coordination of muscular activity and the question then arises as to what functional importance the projection of the splanchnic nerve delta fibres demonstrated here can be accorded. Does it signal the transmission

of a reflex within the autonomic nervous system? No influence from the cerebellum on the abdominal viscera has been demonstrated. A certain degree of cerebellar influence on vasomotor and carotid sinus reflexes as well as on the pupils and nictitating membrane has, however, been shown to exist (MORUZZI, 1950). The importance of the vascular bed in the splanchnic region for the regulation of the arterial blood pressure has long been known, likewise that the chemo-reflexes and pressor-reflexes elicited from the sinus region have their most important efferent pathway in the thoraco-lumbar autonomics. A reflex arc, splanchnic nerve-cerebellum-bulbar vasopressor centres would be conceivable. It has not, however, been demonstrated that *afferent* impulses in the splanchnic nerve normally play an important part in the blood pressure regulation, nor does the part played by the cerebellum in this connection seem to be important. That the demonstrated representation of abdominal visceral afferents in the cerebellum should have this functional significance would, therefore, seem to be remote.

A cerebellar representation for pain has not been shown earlier. One of the difficulties in the study of the representation of, for example, pain and temperature modalities, is to obtain an adequately synchronous afferent volley with physiological stimulation to permit a recordable evoked potential. Tactile, auditory and visual stimuli offer better possibilities. As shown above, there is a possibility that the impulses which travel from the splanchnic nerve to the cerebellum are of nociceptive type, in which case there exists a cerebellar representation for visceral pain. Such a representation would seem very likely and one would expect that also somatic pain is represented in the cerebellum in view of the function of this organ as coordinator of muscular activity and its probable role as "the great modulator of neurologic function" (SNIDER, 1950). The experimental results described in section B indicate that also the delta fibres in somatic afferent nerves possess a cerebellar representation, and thereby give support to the last-mentioned hypothesis.

SUMMARY

1. Electrical stimulation of afferent neurones distributed with the sympathetic outflow to the abdominal viscera evokes responses in the cerebellar cortex. In light anaesthesia these potentials are widely distributed in the cerebellar area explored, though with clearly differentiated maxima: one in the ipsilateral half of the posterior part of culmen, one in the ipsilateral paramedian lobule and one in the contralateral paramedian lobule.

2. The cerebellar responses are not secondary to reflex movements of the trunk musculature which are elicited at the same stimulus strength as that required to evoke the cerebellar responses.

3. The A beta group of splanchnic afferent fibres do not give rise to the cerebellar responses. These appear first at a stimulus strength which activates delta fibres with conduction velocities ranging from 24 m/sec. to about 15 m/sec. Activation of these delta fibres has been shown to produce also certain nociceptive reactions: pupillary dilatation, arterial blood pressure increase and reflex contraction of the abdominal and lower intercostal muscles. Consequently, it seems possible that the impulses mediated by the afferent fibres of the splanchnic cerebellar projection system are of nociceptive type.

4. In leads from the dorsum of the spinal cord no slow negative potentials can be recorded on activation of solely A beta fibres of the splanchnic nerve. On stimulation of the delta fibres, however, a negative dorsal cord potential is recorded. The significance of these results is discussed with regard to the central connections of the splanchnic afferent fibres in the spinal cord.

5. The ascending spinal pathway which transmits the afferent inflow from the splanchnic delta fibres to the receiving areas in the cerebellar cortex proceeds in the anterior quadrant of the spinal cord. The fibres which convey impulses to the contralateral paramedian lobule decussate in the spinal cord.

Responses to stimulation of the afferent delta fibres in the splanchnic nerve can be led off from the inferior cerebellar peduncles on both sides. It seems probable that the afferent impulses are transmitted to the cerebellum by these peduncles.

6. Stimulation of a lower intercostal nerve evokes responses in the cerebellar cortex which are distributed to the same area in the anterior lobe as the responses of splanchnic origin. When the responses from these two sources are evoked simultaneously a high degree of occlusion occurs. By using a conditioning stimulus to the intercostal nerve which was subliminal for the cerebellar response it was possible to show that a blocking interaction occurs between the two afferent volleys at a subcortical level.

When the splanchnic nerve and an intercostal nerve were used in conditioning experiments and the action potentials were recorded from the dorsum of the cord, a fairly high degree of occlusion could be demonstrated. Since occlusion is generally regarded as a sign of neuronal sharing, it is concluded that some visceral afferent delta fibres converge with somatic afferent fibres to end on the same postsynaptic structures of the spinal cord.

7. Stimulation of high threshold fibres in various peripheral branches of the facial nerve evokes responses in the cerebellar cortex. The afferent impulses have been shown to enter the brain stem by way of the vagus nerve. Stimulation of these fibres also gives rise to nociceptive reactions.

Selective activation of the delta fibres of a cutaneous nerve also evokes cerebellar responses. In these experiments the coarse fibres were blocked at the anode.

It is suggested that the high threshold somatic afferents mediating the cerebellar responses transmit nociceptive impulses.

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